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Science Focus

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WHAT WE KNOW ABOUT THE MEGALODON

HABITS

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PLUS

MICHAEL MOSLEY'S 10 HABITS that will help you live longer, feel happier and age well

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IN THIS ISSUE

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Giles Yeo explains why the paleo diet is a Flintstones fantasy

Environment
What's at stake if we mine the deep sea

Nature
The terrifying world of animal mouths

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FROM THE EDITOR

I've long been fascinated by the habits of some of the world's most successful and prolific writers. How are they able to work at such a level, so consistently? Especially since writing has always been such a capricious pursuit for me: easy one day, torture the next.

There's one answer to this question that has stuck with me since I first read it over a decade ago. It comes from author Haruki Murakami.

"When I'm in writing mode for a novel, I get up at 4am and work for five to six hours. In the afternoon I run for 10km or swim for 1,500m, or both. Then I read a bit and listen to some music. I go to bed at 9pm. I keep to this routine without variation. The repetition itself becomes the important thing; it's a form of mesmerism. I mesmerise myself to reach a deeper state of mind. But to hold on to such repetition for so long – six months to a year – requires a good amount of mental and physical strength."

I can't put my finger on it, but there's something about the simplicity of this that speaks to me. If only I could say no to lie-ins, force myself to run every day, resist the temptation of wine with dinner and, of course, get to bed early, then I'd be sorted. On the one hand, it seems so simple, and yet, on the other, I don't think I can get up at 4am unless I have a plane to catch.

So what is it about good habits that lead to such impressive results, and how do we go about forming them when the world conspires against us? We asked cognitive neuroscientist Dr Christian Jarrett to explain how habits form, and how to break the bad ones and make good ones. Plus, we've got Dr Michael Mosley to outline the habits that'll make the biggest difference to your health and wellbeing.

Daniel Bennett

Daniel Bennett, Editor

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What should I do if I get stranded on Snake Island??
→p72

CONTRIBUTORS

DR HELEN SCALES
With companies eager to start drilling, marine biologist and writer Helen talks to us about deep-sea mining and the problems it might create. → p24

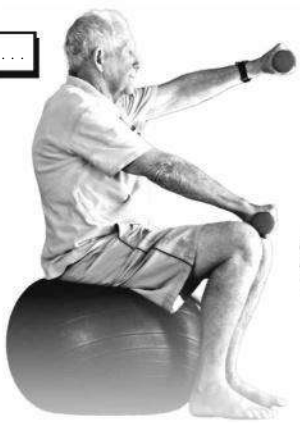
PROF STEPHON ALEXANDER
Theoretical physicist Stephon explores the idea that the Big Bang may not have been the beginning of the Universe. →p28

DR KATE DARLING
MIT Media Lab research scientist Kate explores our relationship with artificial intelligence and explains why it probably isn't cool to kick robots. →p30

DR MICHAEL MOSLEY
When it comes to health advice, Michael is our go-to guy. He shares his top 10 easy-to-adopt habits to help you upgrade your wellbeing. →p64

ON THE BBC THIS MONTH...

CrowdScience: Why are spices delicious?
Anand Jagatia heads to the historic naval city of Portsmouth to explore when spices first reached UK shores, why we're hardwired to love them and whether there are any nutritional benefits to eating them.
BBC World Service, 18 August, 8:30pm (BST)
Also available on BBC Sounds



Just One Thing with Michael Mosley
Dr Michael Mosley looks into – and tries out – the best foods, exercises and lifestyle habits for keeping you healthy and happy.
BBC Radio 4, 16 August, 8:45pm
Available on BBC Sounds

Earth
In case you missed it, Chris Packham tells the violent story of Earth's formation: how it was born out of fire, froze into a snowball and eventually became a lush, green paradise. It's a blockbuster, must-watch exploration of this planet's history.
Catch-up on BBC iPlayer

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CONTENTS

REGULARS

06 EYE OPENER
The best science images from around the world.

12 FEEDBACK
A selection of the physical and electronic mail that has arrived this month.

15 DISCOVERIES
All the month's biggest news: A new modelling technique lets us hear the sound of stars twinkling; AI could provide an early warning system for viral outbreaks; Medics find antibacterial properties in honey made by ants; Radio waves heard coming from star thought to be too cold to produce them; New close-up imaging technique shows the human intestine in unprecedented detail.

26 PROF GILES YEO
Fans of the paleo diet might strive to eat like a caveman, but they'll never be able to digest like one.

28 PROF STEPHON ALEXANDER
Big Bangs, Big Crunches and Big Bounces... physicists are questioning how the Universe began.

30 DR KATE DARLING
Sure, you can treat a robot like dirt if you want to. But you'll be hurting yourself in the long run.

32 REALITY CHECK
The science behind the headlines: The Met Police's use of live facial recognition; Why skin cancer cases are on the rise; Is climate change making hay fever worse?

39 INNOVATIONS
The hottest trends shaking up the tech world.

72 Q&A
Our experts answer your questions. This month: What should I do if I get stranded on Snake Island? What is blue lava? And more...

82 THE EXPLAINER
Sharks: paddle about in the astounding biology and history of these apex predators .

89 CROSSWORD
Engage your grey matter!

89 NEXT MONTH
A sneak peek at the next issue.

90 POPCORN SCIENCE
This isn't the explanation of the Force you're looking for.

46
SUBSCRIBE TODAY!

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15
DISCOVERIES

Twinkle, twinkle, litte star. How I wonder what you... sound like. Well, now we know.

32
REALITY CHECK

Live facial recognition is already in use despite concerns over its accuracy and bias.

72
Q&A

FEATURES

48 SAY AHH...
Check out this selection of some of the oddest gobs in the animal kingdom. Guaranteed to leave you agape.

56 THE POWER OF HABIT
Whether they're good or bad, habits can have a profound effect on your life. But understanding a little of the psychology behind them, can help you make or break them.

66 A DISASTER WAITING TO HAPPEN
The space around Earth is filling up with satellites, both functional and defunct, jeopardising our continued use of it. But there are plans afoot to clear up the potentially catastrophic mess.

39
INNOVATIONS
This month's coolest new gadgets, from action cameras to barbecues (via dictaphones).

26
PROF GILES YEO

"THE REALITY IS HUMANS ARE LIKE COCKROACHES, ADAPTING WHEN WE HAVE TO"

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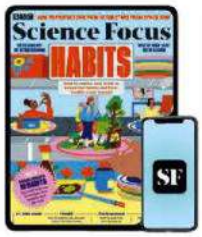

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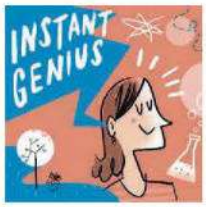

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EYE OPENER

Birthday wishes

This is the Rho Ophiuchi cloud complex. It's the closest star-forming region to Earth – around 390 light-years away – and in stellar nursery terms, it's a rather small, quiet region. But not to the James Webb Space Telescope, the most powerful telescope ever launched, which captured this spectacularly detailed image of the chaotic turmoil within the nursery to celebrate its first anniversary of observations.

Dominating the lower half of the picture are the wispy swirls of a stellar cave. The cream-coloured dust forming the cave is a mix of polycyclic aromatic hydrocarbons (PAHs). These carbon-based molecules are among some of the most common compounds found in space and they're being blasted away by the stellar winds coming from S1, the biggest and brightest star in the centre of the dust cave. S1 is the only star in this image significantly more massive than our Sun.

The red areas, above and to the right, are bipolar jets of molecular hydrogen that have shot out when a young star escaped the confines of its natal envelope.

NASA/ESA/CSA

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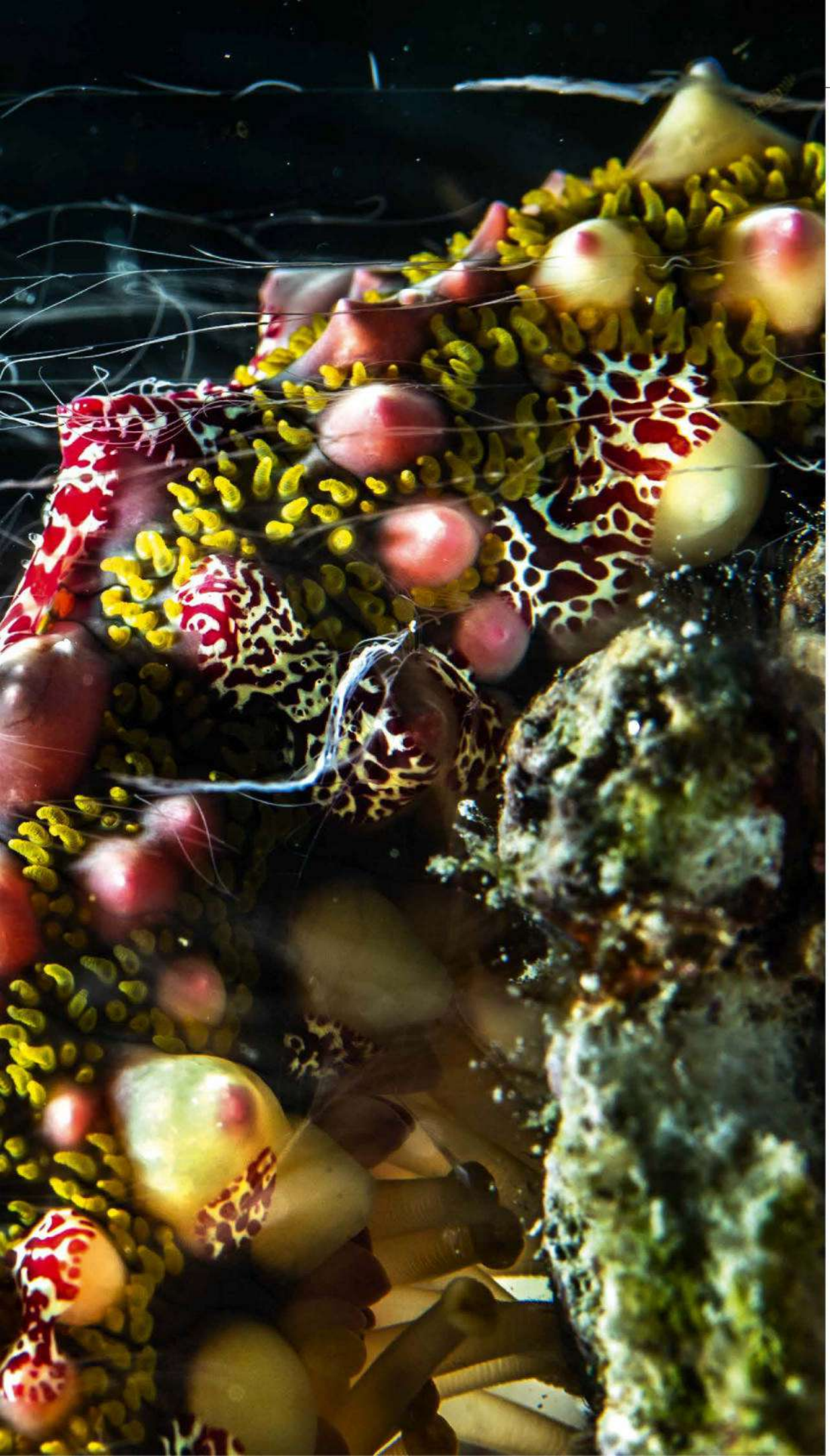

EYE OPENER

Let's work together

RAJA AMPAT, INDONESIA

There's a reason they call the ocean Earth's unexplored frontier. Dive into any of this planet's waters and you soon discover an entirely different ecosystem, populated with strange and unexpected species. One such species (or rather, pair of species) is the extraordinary combination of starfish and a comb jellyfish you see here.

The pink and white warts you see poking up through the tiny green tentacles belong to an *Echinaster callosus*, or warty sea star. These five-armed sea creatures can grow up to 26cm (10in) in diameter. But this one's not alone; it's become host to a creeping comb jellyfish (*Coeloplana astericola*) – the patterned red-and-white blobs you can see spread around and over the warts.

The two have formed a symbiotic relationship, although the jellyfish gets the better part of the deal, living both on and within the body of the host starfish.

The fine, white hair-like structures you see are the jellyfish's sticky tentacles. These can be extended and retracted to capture prey.

RUSSELL LAMAN

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EYE OPENER

Show your stripes

DOVER, UK

Pictures may tell a thousand words, but this one goes even further. These stripes appeared along Dover's White Cliffs on 21 June, as the iconic landmark was gradually turned into a scientific graphic. The stripes represent the average annual temperatures of the UK over the last two centuries, and show how they've risen.

The stripes were created by Prof Ed Hawkins, a climate scientist at the University of Reading, using data from the Met Office. "The climate stripes are simple, stark and easily understandable with a single glance," Hawkins told *BBC Science Focus*.

"The White Cliffs of Dover are an instantly recognisable landmark and offer the perfect blank canvas to 'paint' with the warming stripes. We hope that other landmarks may want to follow this lead and start a climate conversation by lighting up with the climate stripes."

The stripes appeared on the Cliffs towards the end of the hottest June on record, which was followed by deadly heatwaves across Europe and the US in July.

UNIVERSITY OF READING/ED HAWKINS

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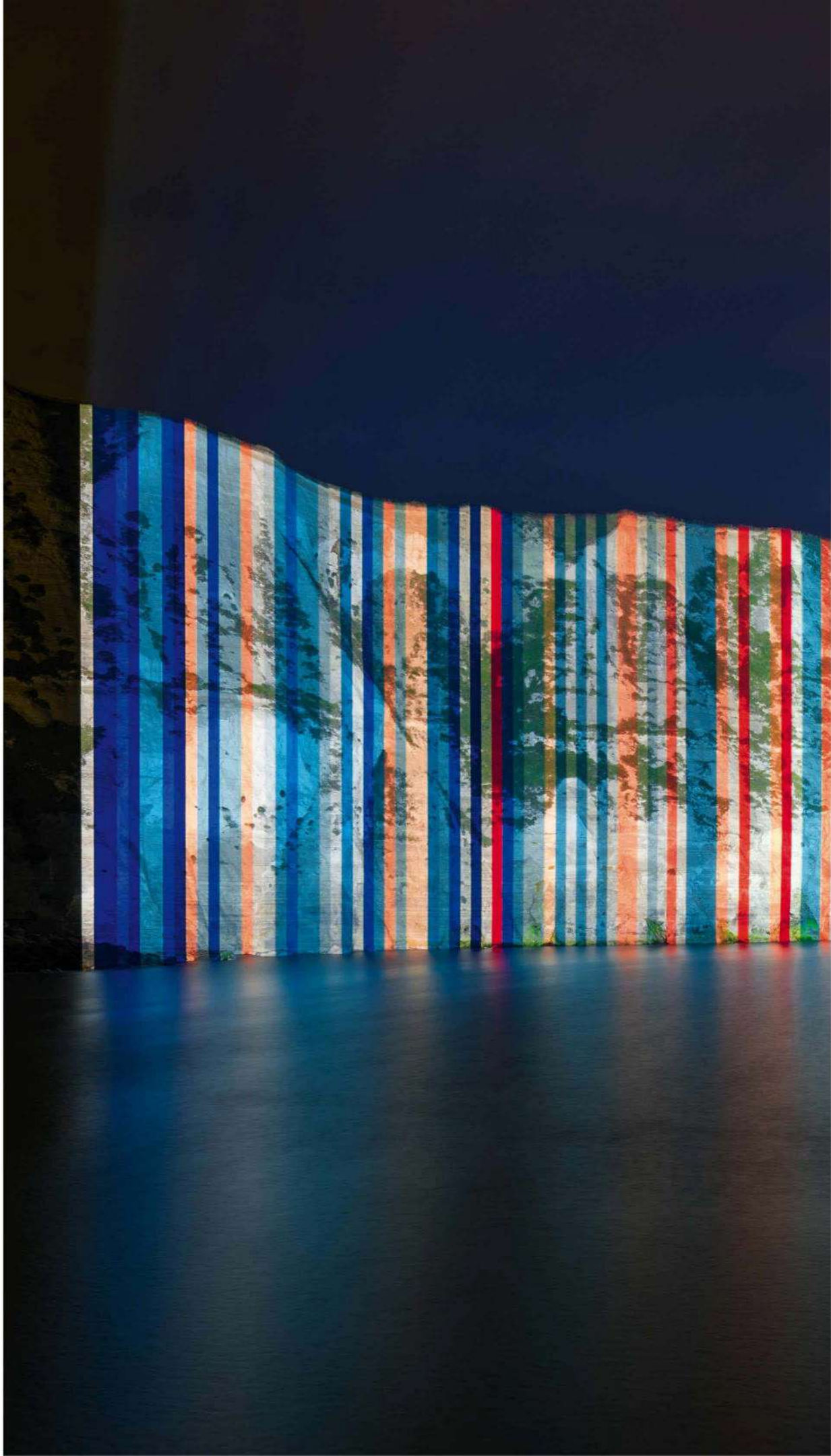

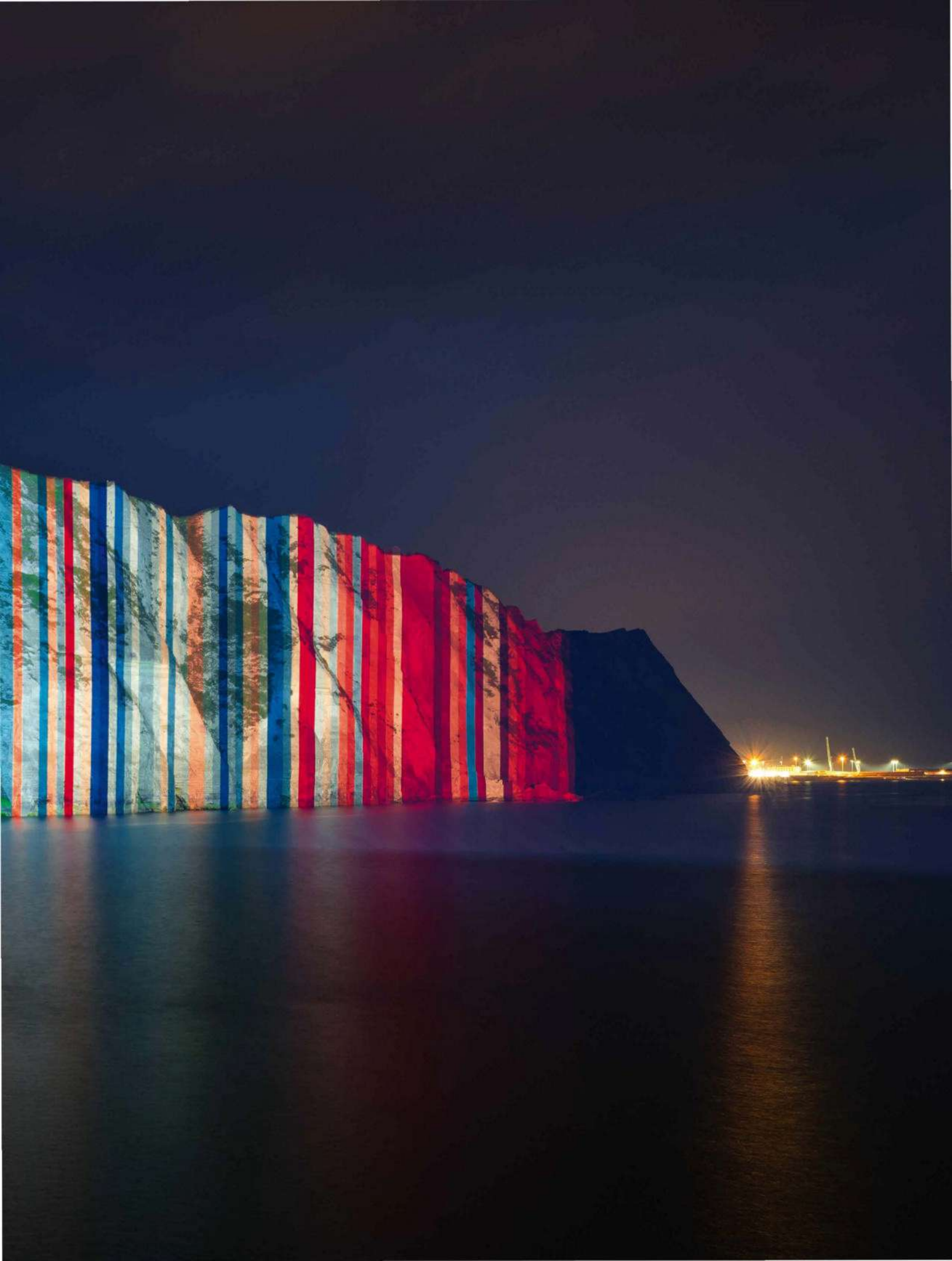

FEEDBACK

YOUR OPINIONS ON SCIENCE, TECHNOLOGY AND OUR MAGAZINE

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LETTER OF THE MONTH

Say what?

I found Dr Kate Darling's column 'AI-generated email may be convenient, but it could kill off endangered languages' (July, p32) very interesting. But it strikes me that artificial intelligence also offers an opportunity to preserve endangered spoken languages, and even revive some lost ones. Having seen some of the amazing results of AI restoring and colourising old film, including sound, surely an AI would be able to determine what some endangered or lost spoken languages sound like?

Danny Herbert, via email

Dr Kate Darling replies...

I agree that AI could be incredibly helpful in preserving languages. But to preserve the diversity of written Swiss-German (and similar dialects), the training data would almost need to be at the level of an individual person's writing style, which I'm not sure is possible. That said, there are many cases of rare languages that are more standardised, where AI provides some fantastic opportunities for restoration and preservation.

WRITE IN AND WIN!

The writer of next issue's *Letter of the Month* wins ***a trio of hardback science books***. Put pen to paper (or fingertips to keyboard) and you could get your hands on *Fevered Planet* by John Vidal; *We Are Electric* by Sally Adee; and *The Everything Blueprint* by James Ashton.

Eyesight to the blind?

In the Discoveries story about the optical illusion (July, p18), you write that the eye compresses information, while the neurons fire and send signals to the brain. Does this mean that our eyes encode visual information into data packets and, if that is the case, might one day an artificial eye be able to do the same for blind people?

Alan Thomas, Surrey

Ant-Man... and all that jazz

Quantum physics puts my brain into a dizzying spin at the best of times. But having found no answer in Ant-Man's latest movie adventure into the quantum world, it's good to read that perhaps jazz holds a few clues (July, p30). However, considering Richard Feynman's 'path integral' and Erwin Schrödinger's work, does this mean that before I walk into Ronnie Scott's Jazz Club, Prof Stephon Alexander and Donald Harrison are playing every possible note until I open the doors and experience the music for myself? I think I need to sit down again.

Paul Mellor, St Albans

Questions remain regarding Ant-Man's approach to quantum physics

"PEOPLE WILL READILY TREAT ANY AGENT THAT MOVES LIKE IT'S ALIVE, EVEN A RANDOMLY MOVING STICK"

DR KATE DARLING, p30

Scientists have been warning the world's leaders about the climate crisis for decades

GETTY IMAGES X2, SHUTTERSTOCK

The call to act is going unheard

In his article 'Could AI save us from extinction?' (July, p64), Lord Martin Rees talks about the threat of global warming and predicts that politicians will not react sufficiently quickly to it. He then goes on to say: "If science is to save us, we need to think globally, rationally and long-term." But there seem to be very few signs that is likely.

If climate change is a real emergency – and I think it is – surely more should be done? Lord Rees seems to think science could save us. Yet, currently, the scientific case for climate change, which is surely well-proven by now, has failed to galvanise the world's politicians into taking much coordinated international action.

Scientists need to find a way to make their arguments more powerful, or those predicting that the any action that's taken will be too little too late, will be right.

As the American actress Lily Tomlin said: "Things are going to get a lot worse, before they get worse."

Patrick Forsyth, Essex

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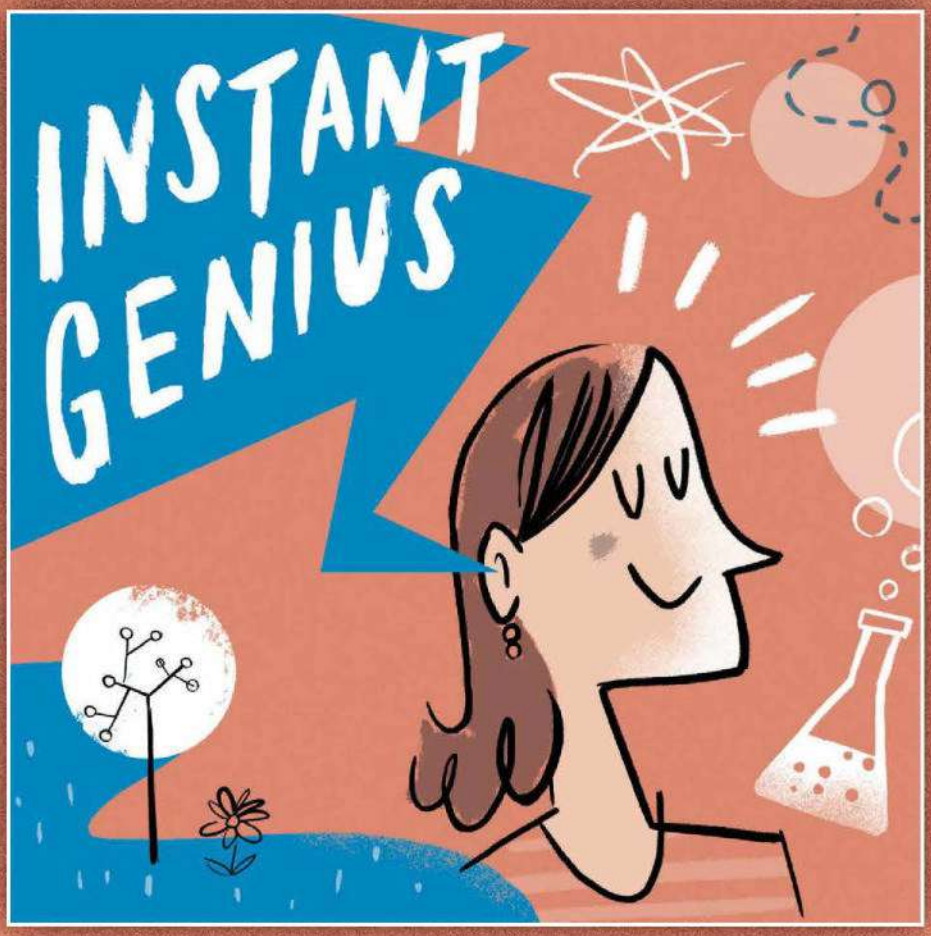

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with
Dr Helen Czerski

"It's very rare to find ultra-cool brown dwarf stars like this producing radio waves"
Kovi Rose **p21**

DISCOVERIES

ASTRONOMY

THE SONG OF STARS

A new modelling technique lets us listen to the twinkling of stars and the 'sounds' produced by the violent nuclear reactions in their cores **p16**

VIROLOGY

PANDEMIC PREDICTION

AI has potential as an early warning system for viral outbreaks **p18**

MEDICINE

OLD REMEDY, REDISCOVERED

Medics find antibacterial properties in honey produced by ants **p19**

BIOLOGY

FOOD FIGHT

Unborn babies battle their mothers for more food... and it's dad's fault **p20**

ASTRONOMY

NOT TOO COOL FOR RADIO

Radio waves heard coming from star thought too cold to produce them **p21**

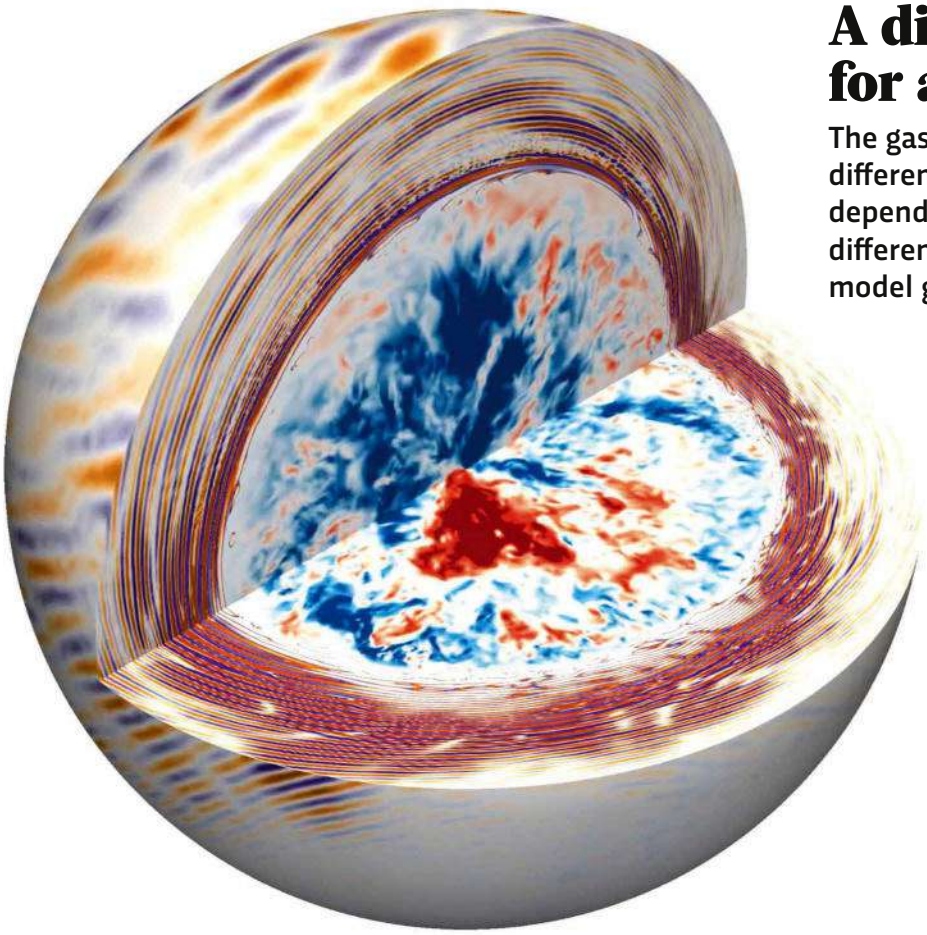
MEDICINE

YOUR GUTS CLOSE UP

New imaging technique shows human intestine in unprecedented detail **p22**

NASA/ESA/CSA

You might know what a twinkling star looks like, but a new technique enables us to hear what they 'sound' like



A different song for a different size

The gases in a massive star's core create different frequencies and intensities of waves depending on its size or brightness. Those differences are reflected in the 'songs' the model generated for each type of massive star

Large massive star
(40 TIMES MORE MASSIVE THAN THE SUN)

What initially sounds like the blast from a ray gun in a sci-fi film, gradually warps to become, a low, resonant thrum (like the sound of jet engines heard inside an aeroplane cabin).

Medium massive star
(15 TIMES MORE MASSIVE THAN THE SUN)

The scientists behind the audio simulations describe the waves for this size of star as a "persistent hum through a windswept terrain."

Small massive star
(3 TIMES MORE MASSIVE THAN THE SUN)

The eerie of the three, the sound of a smaller star's inherent twinkle translates as a high-pitched, plaintive ringing – a little like a warning siren.

ASTRONOMY

EERIE 'SONG' OF TWINKLING STARS DRIVES UNDERSTANDING OF THEIR NUCLEAR CORES

Taking a musical approach helps scientists determine how much a star should shine

ABOVE One of the 3D simulations of the gas waves moving from a star's core to its surface

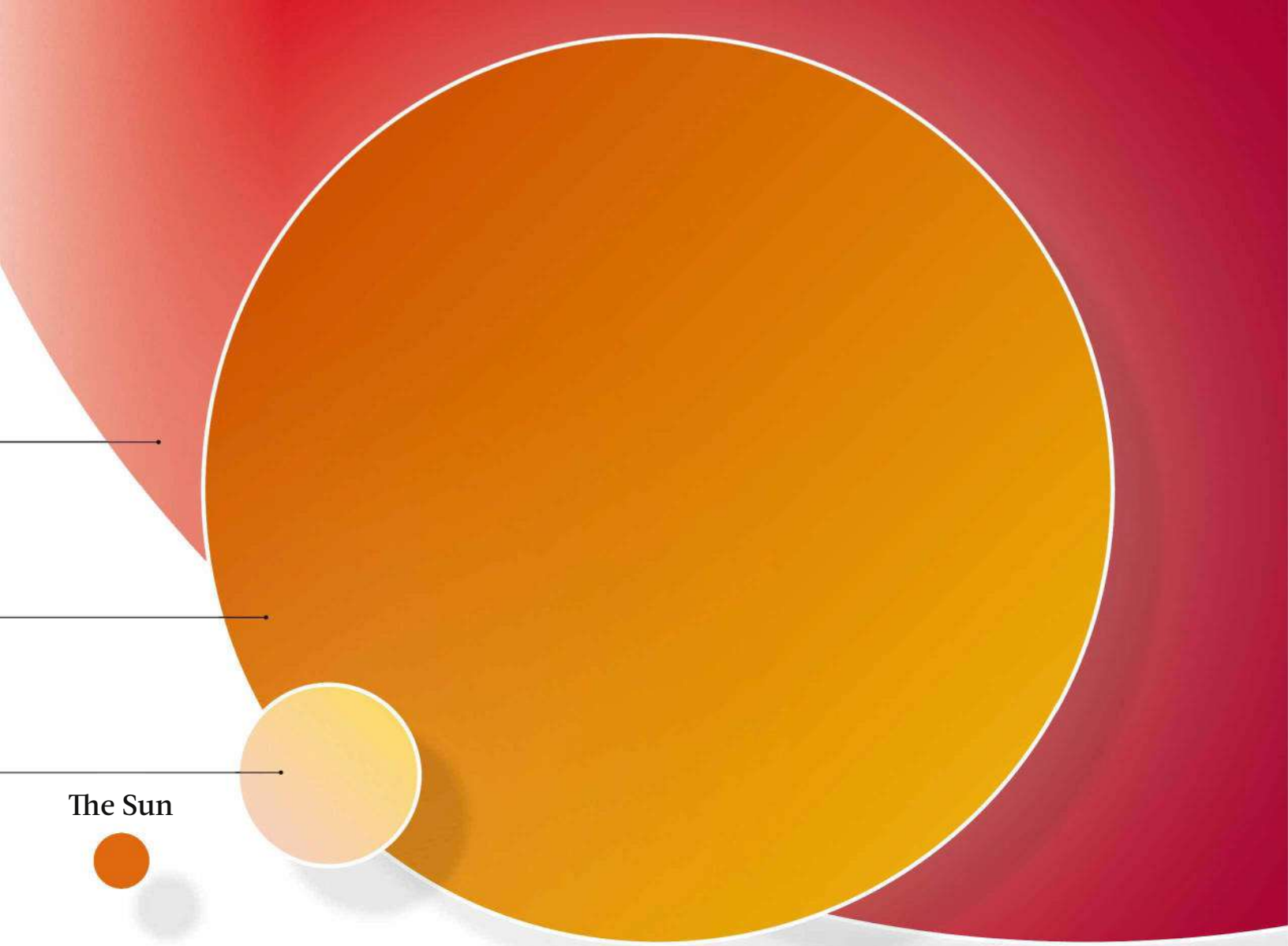
Scientists have developed a new method to predict the brightness of a star's inherent twinkle. What's more, they've also managed to simulate how that twinkle might sound. And it seems that massive stars sing a strangely eerie song (hear an example for yourself on the *BBC Science Focus* website at bit.ly/InherentTwinkle).

Unlike the visible twinkle we see from Earth, which is caused by a star's light being distorted as it passes through this planet's atmosphere, a star's inherent twinkle is caused by rippling waves of gas on its surface.

The gas waves originate in the nuclear reactions that take place in a star's core and move out towards the surface. As they move, the waves create turbulence and chaos in the gases around them, increasing or decreasing the star's shine to produce its inherent twinkle. This inherent twinkle is invisible, however – to the naked eye as well as the current generation of powerful ground-based telescopes.

But a team, led by scientists from Northwestern University in Illinois, America, has developed a method to produce 3D simulations of the gas waves moving from a star's core to its surface. These simulations have, for the first time ever,

NORTHWESTERN UNIVERSITY ILLINOIS



enabled the scientists to determine a given star's inherent twinkle.

The new method, which was detailed in a study published in the journal *Nature Astronomy*, may help us learn more about what's happening inside massive stars (those more than 1.2 times larger than the Sun). Furthermore, it has the potential to shed light on how stars and galaxies form and evolve, as well as help explain how the elements we depend on – such as oxygen – are created.

"Motions in the cores of stars launch waves like those on the ocean," said Dr Evan Anders, who led the study. "When the waves arrive at the star's surface, they make it twinkle in a way that astronomers may [one day] be able to observe."

But how did they come up with the sounds of those stars' twinkles?

After developing the simulations into computer models and using the models to calculate how much twinkling is caused by different frequencies and intensities of waves, Anders and his team then converted these calculations into an audio track to illustrate the movement of the waves.

The resulting track is a human 'translation' of the song, however, because the waves are outside the range of human hearing. As such, the researchers had to increase the frequencies of the waves in order to make them audible.

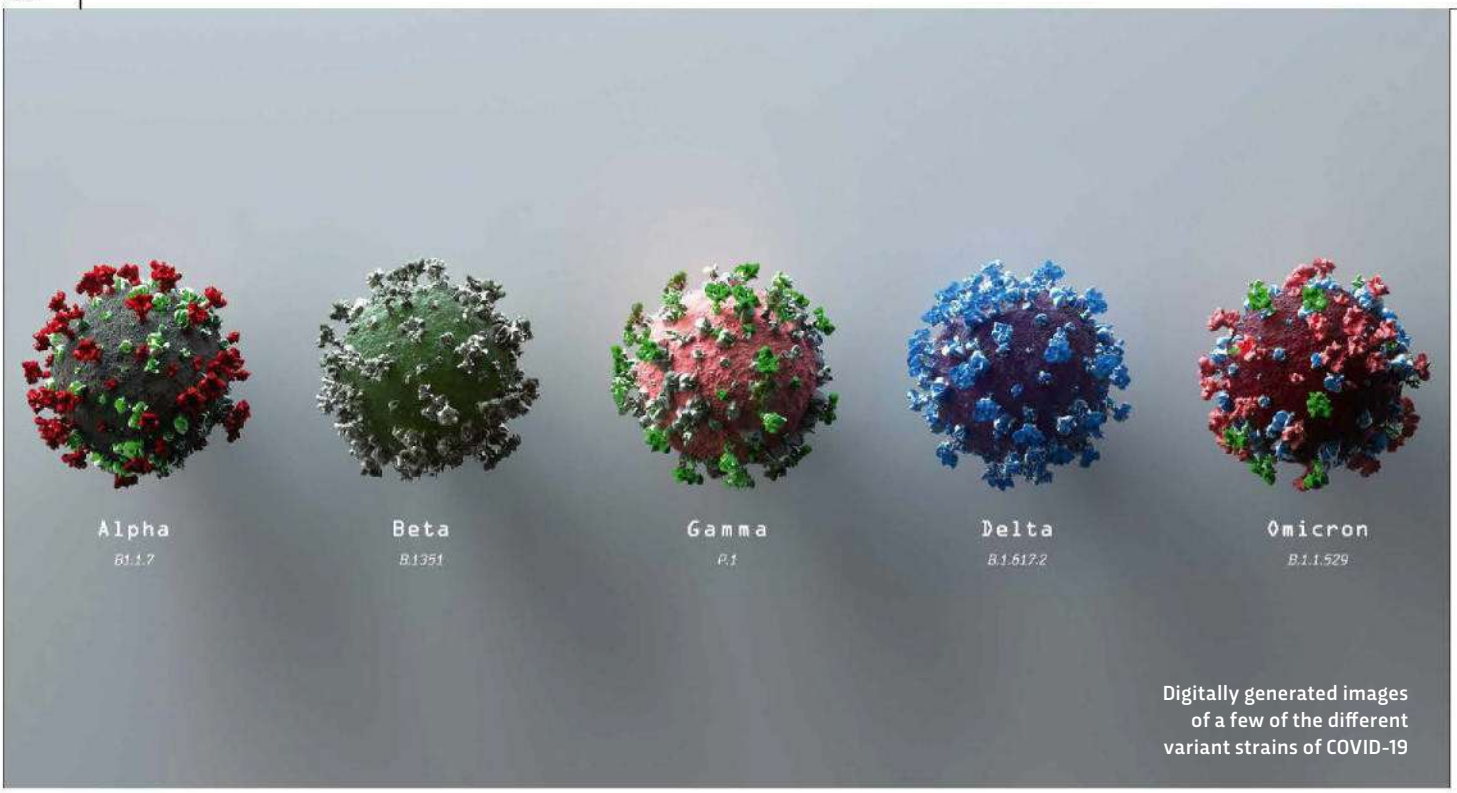
The sound of the chosen star's inherent twinkling has a clear, commanding ring with an eerie, reverberating pulse underneath. The pulse represents the movement of the waves from the core out to the star's surface.

Studying the calculations in audio form allowed the scientists to combine two processes that operate on different timescales: the initial turbulence of the gases colliding, which happens over a matter of weeks; and the waves themselves, which reverberate for hundreds of thousands of years.

This new method developed by Anders and his team will help to direct powerful future telescopes towards the inner regions of stars where heavier elements are forged.

"This study provides an out-of-the-box method to search for stars' signatures that are largely masked and invisible even to more powerful telescopes and to the human eye," Dr Wanda Díaz-Merced, a sonification astronomer who was not involved in the research, told *BBC Science Focus*.

"I congratulate the team!"



Digitally generated images of a few of the different variant strains of COVID-19

VIROLOGY

NEW AI COULD IDENTIFY VIRAL 'DARK MATTER' OF NEXT PANDEMIC

The early warning system is based on machine learning and could have predicted the emergence of the COVID variants

Artificial intelligence (AI) could reduce the threat of future viral pandemics, that's according to the scientists who have developed an early warning system that uses machine learning.

The scientists from the Scripps Research Institute, which is spread across the US but has its headquarters in California, have trained the system to track the emergence and evolution of epidemic viruses, such as the SARS-CoV-2 variants.

This system could be used to track viral pandemics in the future, using an 'unprecedented' approach – according to the paper's senior author Prof William Balch. "There are rules of pandemic virus evolution that we have not understood, but can be discovered," he said.

In a paper published in *Cell Patterns*, the scientists show this system could have predicted new COVID variants weeks before the World Health Organization (WHO) designated them as threats.

"One of the big lessons of this work is that it's important to take into account not just a few prominent variants, but also the tens of thousands of other undesignated variants, which we call the 'variant dark matter'," said Balch.

> **"This system could be used to track viral pandemics in the future"**

The AI was able to identify the key variants emerging from the 'dark matter', meaning those that significantly affected viral spread and mortality rates.

When applying the AI to data from the COVID pandemic, the machine was able to track genetic changes in the variants, as well as the virus's response to lockdowns, mask wearing, new vaccines, increasing human immunity and competition between different variants.

The scientists hope their findings show that similar early warning systems could track the evolution of future viral pandemics in real-time. This could help scientists to predict increases in infection rates and allow them to prepare countermeasures, such as mask wearing and healthcare service provisions.

The AI could also help in the race to find treatments and vaccines during pandemics, as the system also identified key COVID proteins and their roles in the evolution of the pandemic.

"This system and its underlying technical methods have many possible future applications," said Dr Ben Calverley, co-first author of the study.

GETTY IMAGES, ALAMY

MEDICINE

ANT HONEY USED IN INDIGENOUS AUSTRALIAN MEDICINE COULD INSPIRE POWERFUL NEW ANTIBIOTICS

It's a first for Western science, but Indigenous Australians have been using the honeypot ant medicinally for thousands of years

A strange species of Australian ant produces honey with antimicrobial powers, killing bacteria and fungus species, according to a recent study.

The study, conducted by scientists at the University of Sydney, is the first to investigate the medicinal benefits of ant honey. This is not an original discovery, however. Australian honeypot ants have been used in food and medicine by First Nations people for thousands of years.

The Australian honeypot ant, *Camponotus inflatus*, is found in desert areas in Western Australia and the Northern Territory. The researchers hope that identifying the particular antimicrobial compounds in the ant honey could help to develop new antibiotics.

"I have long been fascinated by the honeypot ant and its amazing way of producing and storing honey," said Andrew Dong, co-author of the study published in journal *PeerJ*. "Given the medicinal use of the honey by Indigenous people, I wondered if it might have antimicrobial characteristics."

"Our people have been enjoying sweet honey ants for thousands of years," said Danny Ulrich from the Tjupan language group, who helped the researchers track down the honeypot ants. "As for its medicinal use, we use it for sore throats and sometimes as a topical ointment to help keep infections at bay."

Following the lead of Indigenous people, the scientists profiled the honey to find out its bacterial and fungal microbiome: the composition of good microbes that can tackle the bad ones. They found that the honey's microbiome can inhibit the growth of golden staph, a bacterium that can cause infections or even death if it enters the body through a cut.

The ants have also evolved so that their honey inhibits two fungal species, *Aspergillus* and *Cryptococcus*, which can also cause serious infections in people with suppressed immune systems.

According to the researchers, this honey has a different medicinal mechanism to manuka honey, a dark honey produced by bees that pollinate manuka flowers, which are native to New Zealand. Manuka honey is well known for its antimicrobial properties and can be used as a treatment for wounds and skin infections.

How, and why, does the Australian honeypot ant make honey?

1. One group of honeypot ants, which form 50 per cent of the workforce, play a bizarre role in the wider colony.

2. These worker ants are known as 'rotunds', and they hang upside down from the ceilings of underground chambers within the ants' nest.

3. Here, they're overfed by the other ants who stuff them full of nectar and other sugary substances.

4. The rotunds' abdomens become translucent and orange as they swell up to contain all the honey.

5. The other ants in the nest groom and clean the rotunds to protect their food stock.

6. When food options become scarce for the rest of the colony, the rotunds are tickled so that they regurgitate the honey for the other ants to enjoy on tap.

7. The rotunds are immobilised by their size and eventually grow to the size of small grapes.

BIOLOGY

MOTHERS ARE FORCED TO FIGHT A NUTRIENT WAR WITH THEIR UNBORN BABIES

A study on mice enabled scientists to discover that children inherit 'greedy genes' from fathers

You probably wouldn't dream of demanding more food from your mum, especially if it had to come from her own plate. But new research shows that most of us have done exactly that, and it's all thanks to our dads.

According to scientists from the University of Cambridge, foetuses use the insulin-like growth factor 2 (IGF2) gene, which is inherited from their fathers, to force their mothers to release more nutrients during pregnancy.

According to the scientists behind the research, it's the first evidence that a father's genes allows his unborn child to send these demanding signals.

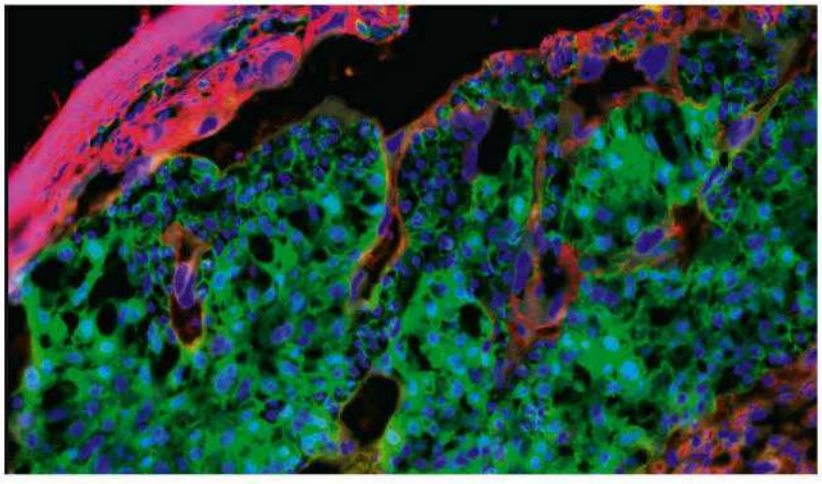
"Genes controlled by the father are 'greedy' and 'selfish' and will tend to manipulate maternal resources for the benefit of the foetuses," said Dr Miguel Constância, a co-senior author of the research.

Paternal genes generally promote foetus growth, whereas those from the mother tend to be more limiting. This means that the greedy signals released by the father's genes kick off an unusual war between the mother and baby.

While the mother's body wants the baby to be healthy, she also needs the same glucose and fats for her own health. These resources will help her deliver the baby, nurse it and then, potentially, have more. But limiting nutrients to the foetus also means the baby isn't too big to come out at the end of the pregnancy.

The research, published in the journal *Cell Metabolism*, was carried out on pregnant mice. The scientists deleted the IGF2 gene in the rodents' placentas. Without the IGF2 gene the mothers didn't make enough of a protein required to grow the foetuses' livers and brains properly.

In the future, the researchers hope that these results could help them develop ways of targeting the placenta to improve the health of mothers and babies.



Placenta cells (in green) carrying the IGF2 gene, which signals the mother to supply nutrients

ASTRONOMY

RARE 'ULTRACOOL' BROWN DWARF STAR FOUND EMITTING RADIO WAVES

Unusual radio signals have led astronomers to a surprising astronomical object

"It's very rare to find ultra-cool brown dwarf stars like this producing radio emissions"

The antennae that form the ASKAP telescope array

It may not be the brightest star, but a brown dwarf is shining for a different reason altogether. Astronomers at the University of Sydney have found the coldest star on record to emit radio waves.

At a mere 425°Cs (797°F), this little ball of gas, known as T8 Dwarf WISE J062309.94−045624.6, is cooler than a typical campfire. The Sun, in comparison, burns at a whopping 5,600°C (10,112 °F).

"Finding this brown dwarf producing radio waves at such a low temperature is a neat discovery," said Kovi Rose, a PhD candidate at the University of Sydney's School of Physics and the lead author of the paper that announced the finding, published in *The Astrophysical Journal*.

According to Rose, "It's very rare to find ultra-cool brown dwarf stars like this producing radio emissions. That's because their dynamics don't usually produce the magnetic fields that generate radio emissions detectable from Earth."

Radio waves can teach us a lot about the composition, structure and motion of astronomical objects. Fewer than 10 per cent of brown dwarfs produce them, however.

The Australian scientists hope that their discovery will deepen our knowledge of ultracool brown dwarfs, including how they evolve and generate magnetic fields.

T8 Dwarf WISE J062309.94−045624.6 lies about 37 light-years from Earth. It's smaller than Jupiter (another rarity for a brown dwarf star), but is between 4 to 44 times more massive than the gas giant in our Solar System. It was originally discovered in 2011 by US astronomers using infrared spectroscopy rather than radio.

This discovery is just one in a series of unusual astronomical objects detected using new data from the Australian Square Kilometre Pathfinder (ASKAP) telescope in Western Australia.

Prof Tara Murphy, a co-author of the paper, said: "As we open this window on the radio sky, we'll improve our understanding of the stars around us and the potential habitability of exoplanet systems they host."

ALAMY X2, SFERRUZZI-PERRI LAB

MEDICINE

SCIENTISTS PRODUCE THE FIRST CELLULAR MAP OF THE HUMAN INTESTINE

Fluorescent antibodies reveal the atlas of cell 'neighbourhoods' that cooperate to protect you

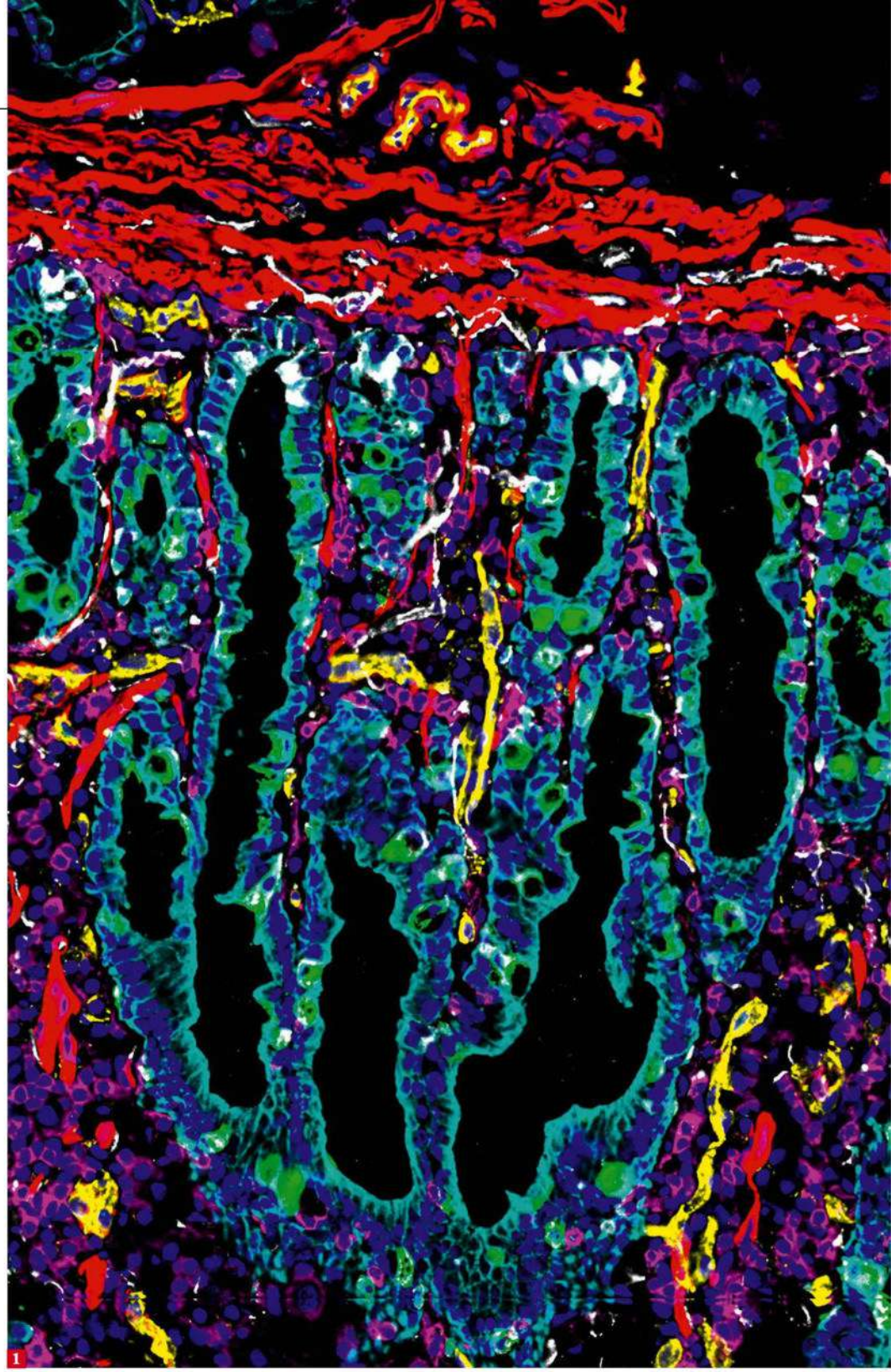
Researchers from Stanford Medicine in the US have used a new imaging technique to map the human digestive system. It's revealed our guts to be a 'neighbourhood' where different cells work together to digest food and fight off invading microbes.

The scientists examined the small and large intestines of nine deceased donors. They imaged them using a technology called 'co-detection by indexing' (CODEX), which involves staining and washing the gut tissue repeatedly with fluorescent antibodies that bind to specific proteins.

By combining CODEX with other new imaging technologies, the researchers were able to map each of these neighbourhoods down to the level of individual cells – a feat that has never been achieved before.

"It was a bit like exploring a new planet, in that we didn't know exactly what cell types we would find or how they would be organised," said Dr Michael Snyder, co-senior author of the research.

Once the gut had been mapped, the researchers were able to identify 20 cellular neighbourhoods in the human digestive system. The researchers hope that these images, published in the journal *Nature*, will be used in a clinical setting to help diagnose conditions such as irritable bowel syndrome and early-stage colon cancer.



1. This highly magnified image shows some of the muscle cells (in red), immune cells (magenta) and proteins (cyan) in the human intestine. It's one the first images to visualise the human intestine at the single-cell level. Doctors could use detailed images, like this, to help diagnose various gastrointestinal conditions.

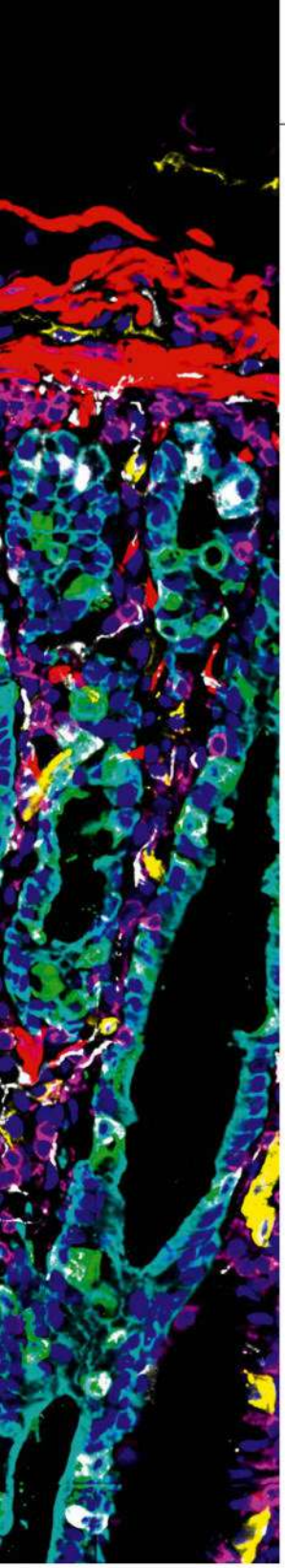
2. Specific cells within the gut were tagged with different colours to highlight various cell types. Some of the cellular groups the CODEX technique revealed in the process of creating this map include the epithelial cells (which make up the intestinal lining), connective tissue cells, nerve cells and immune cells, as well as blood vessels.

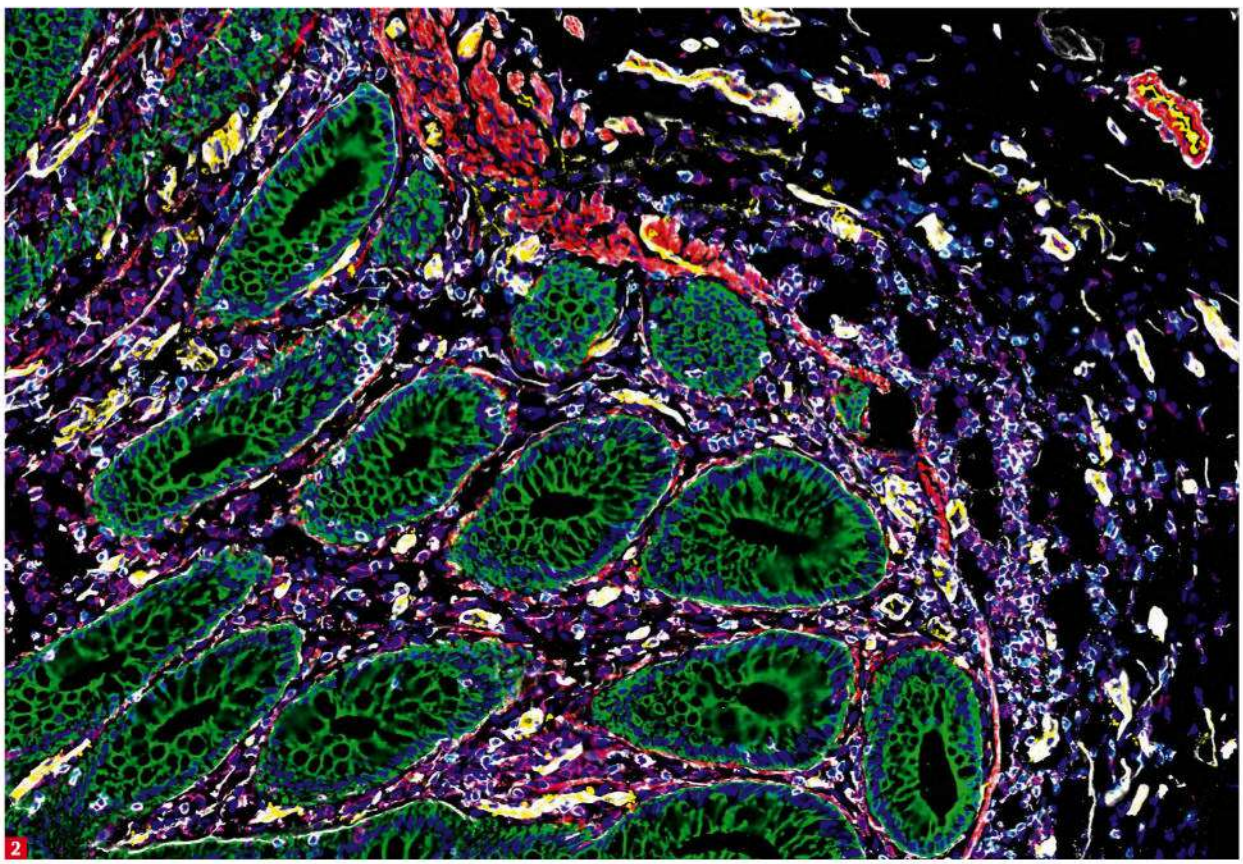
The green areas in this image are cytokeratins, a protein that enables cells to withstand mechanical stress during the digestion process. They're surrounded by immune cells (shown in magenta) and eukaryotic cell nuclei (shown in blue). The red areas show muscle tissue.

3. This is a 'zoomed-out' version of the first image, giving you an idea of the level of detail that can be achieved with the CODEX imaging technique. Once again, muscle cells are shown in red, surrounded by immune cells (magenta), proteins (cyan) and endothelial cells that line the blood vessels (yellow).

Eventually, the research team from Stanford aims to produce a 3D map of the gut to better understand the nerve structures and blood vessels of the digestive system.

STANFORD MEDICINE/SNYDER LAB/ NOLAN LAB/GREENLEAF LABX3





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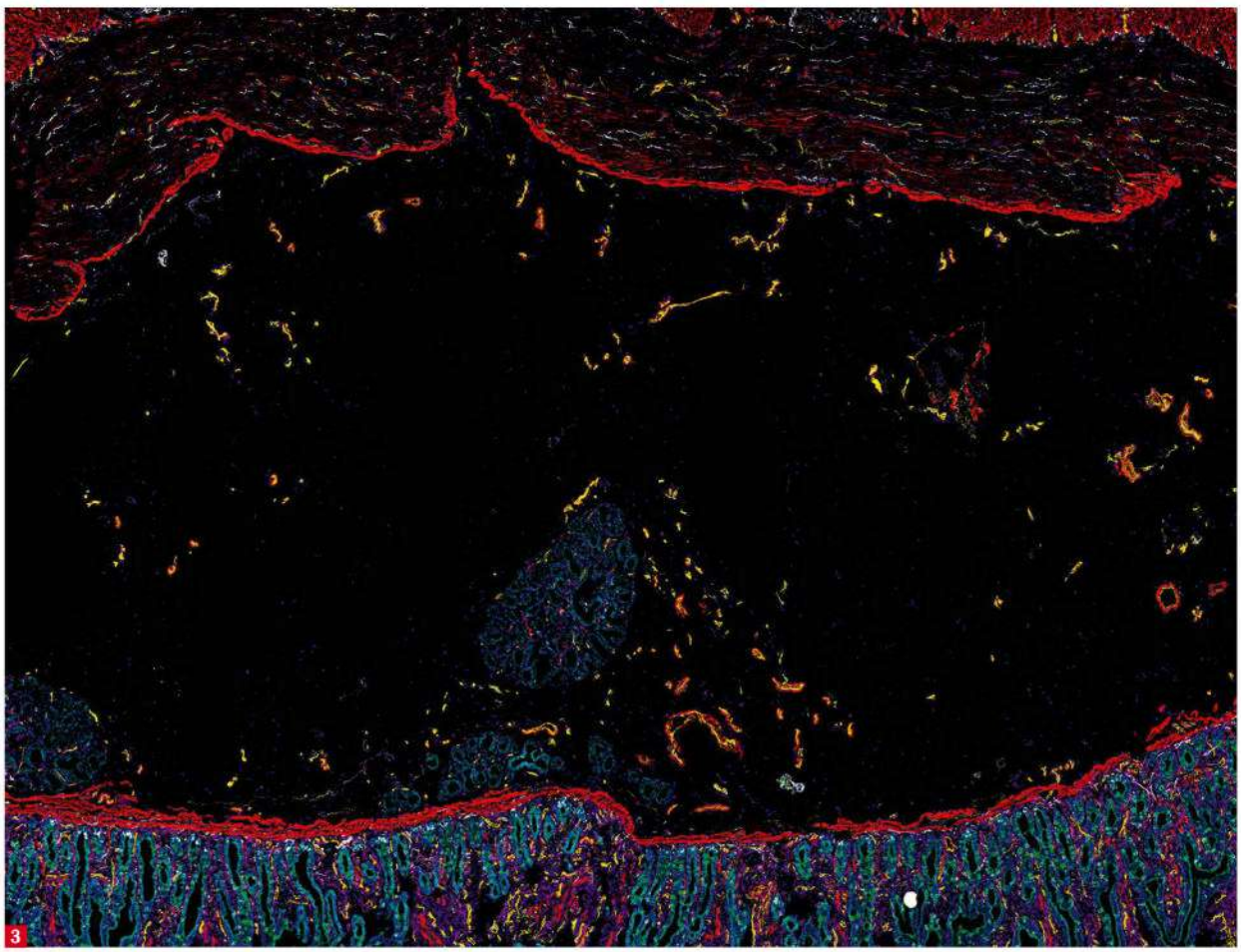


3

PRIMER

DEEP-SEA MINING

Why the next gold rush is happening at the bottom of the ocean

Down past the jellyfish, through the water column and beyond the light is the deep sea: the place between 200 to 11,000m (650 to 36,000ft) below the ocean's surface. The extremely high pressures and cold, dark conditions make unique habitats for the surprisingly colourful life here – bizarre creatures like hairy-chested crabs and glittery Elvis worms.

But some people have their eyes on a different sort of riches formed in these unusual conditions: rare earth metals. Dr Helen Scales explains the drive to mine the materials buried in the deepest parts of the ocean.

THE WORD 'MINING' USUALLY BRINGS UP IMAGES OF GRUBBY FACES IN HARD HATS DISAPPEARING UNDERGROUND. SO WHAT IS MINING WHEN IT'S IN THE DEEP SEA?

It's just as grubby as mining on land – the difference is there aren't people actually in deep-sea mines. It's all going to be done remotely, using similar sorts of camera and robot technologies to those scientists are using to explore the deep sea. Only they'll be much bigger, with mining machinery bolted to them.

There are three main mining targets: polymetallic nodules, seamount crusts and hydrothermal vents.

For mining nodules – these dense lumps of rare metals – imagine a massive digger with caterpillar treads and, on the front, a massive scoop. That scoop is going to stick forks into the seabed and then drag them forwards, pick up the rocks and pop them into a tube – a huge pipe that's several miles long and will suck those rocks up to the surface.

One of the other places people want to mine is seamounts – those enormous mountains covered in metal-rich crusts. To mine these and hydrothermal vents, it'll be the same big digger with caterpillar treads, but with a big mining drill head. One thing that's not yet truly apparent is the scale on which this mining is going to happen.

WHAT ARE POLYMETALLIC NODULES?

They look like lumps of coal, or black potatoes. They're very dense as they're full of metals, so they're incredibly heavy for their size – and they're actually radioactive.

The way they form is fascinating – they basically form from the water itself. It begins with a little fragment of something, such as a shark tooth or a piece of whalebone lying on the seabed. Then over the eons, dissolved minerals and metals in the seawater settle onto those structures and begin to accrete. It takes millions of years for one of the nodules to grow from the size of a pea to the size of a golf ball.

They lie on the soft sediment that forms an ecosystem we used to know very little about. But scientists have been looking at this ecosystem, partly because there's interest in mining the nodules found there.

A recent paper focused on a particular part of the Pacific Ocean called the Clarion-Clipperton Zone, which is where this effort to mine the deep sea is really focusing at the moment. The study showed that there were at least 5,000 species in this particular area of the deep abyss where nodules exist, and nine out of ten of them haven't been found before.

The drilling ship, *Hidden Gem*, owned by offshore energy company Allseas, faced protests as it underwent conversion into a nodule collection vessel while docked in Rotterdam in 2022

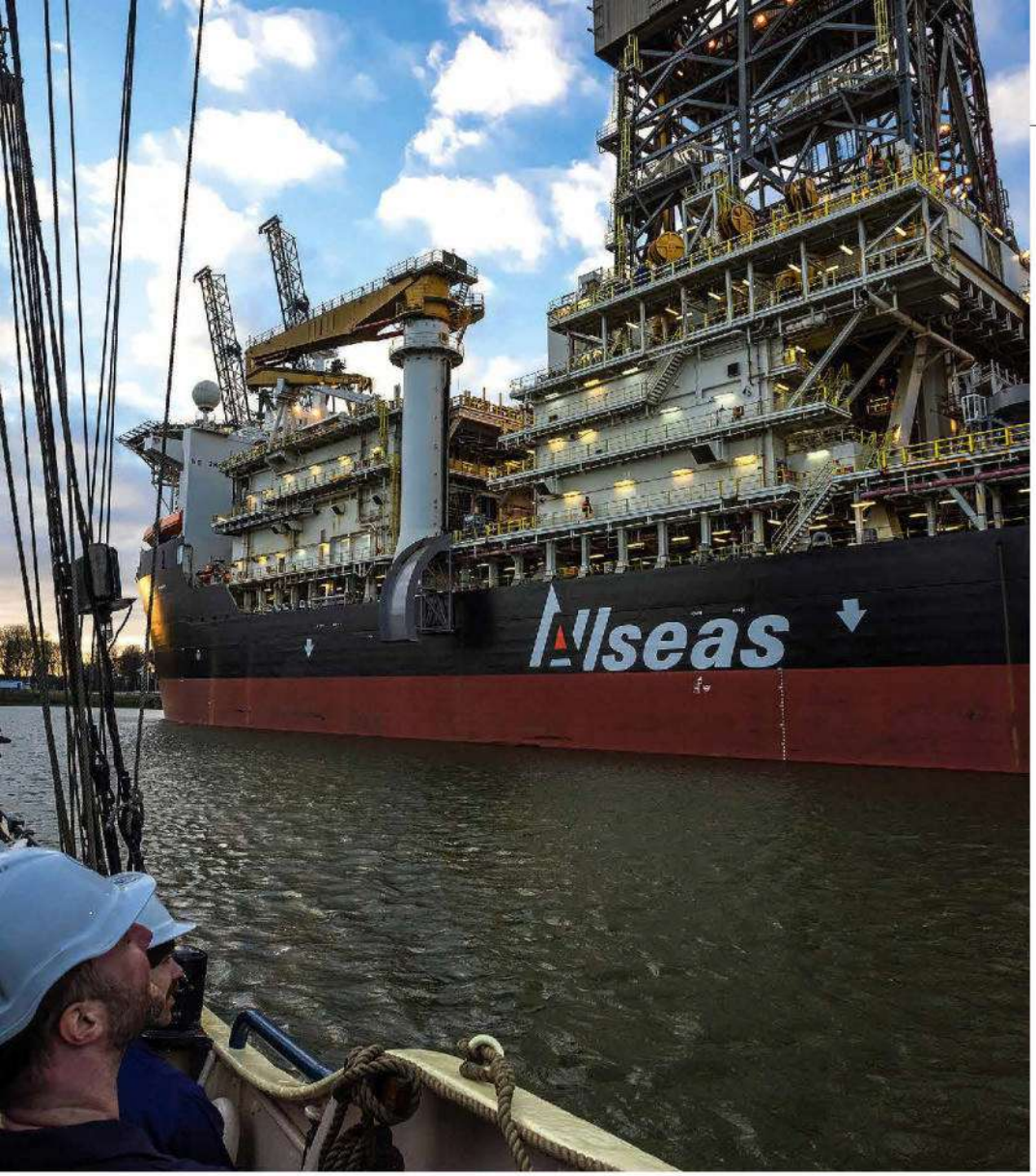
WHAT DO WE WANT THESE METALS FOR? ARE THEY WORTH IT?

We're talking about rare earth metals, as well as elements like cobalt, lithium and nickel. They're being used in various technologies, but the emphasis at the moment is very much on electric vehicles and their batteries.

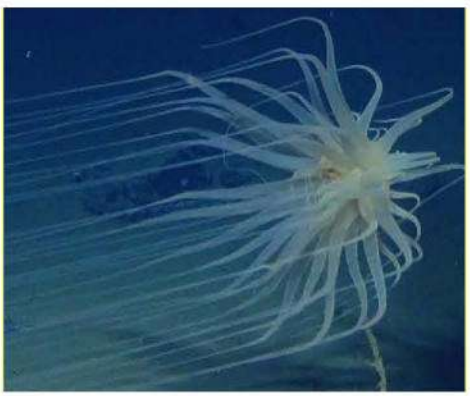
The arguments [for deep-sea mining] are that those metals are going to start becoming more problematic to mine on land. They're certainly not running out – that's a misleading idea, as there are large resources of these metals. But the real question is who's going to extract these metals and how expensive extracting them will be.

Battery technologies are moving on very fast. Just a couple of years ago, the big focus for deep-sea mining was cobalt. Cobalt was certainly needed for the first generations of hybrid and electric cars. But already, we can make batteries without it – just a couple of years down the line.

GETTY IMAGES, CRAIG SMITH/DIVA AMON/ABYSSLINE PROJECT/NOAA X2



***Relicanthus daphneae*, a giant anemone lives 4,100m down in the Clarion-Clipperton Zone**



***Amperima rosea*, a sea cucumber is another species that dwells in the proposed mining zone**

"The study showed that there were at least 5,000 species in this part of the deep abyss... and nine out of ten of them haven't been found before"

There are very fast-moving developments in the kinds of technologies that will hopefully reduce our reliance on fossil fuels, but there's nothing to say that the only way – or, indeed, the best way – to do that will be from mining these deep-sea metals.

I don't think there's a way to mine them lightly enough to not cause damage, because ultimately we're extracting the resource upon which biodiversity depends. It's going to take a good ten years of really intensive, highly funded, coordinated research to get anywhere near to being able to draw up proper, sustainable mining plans.

WHY IS DEEP-SEA MINING SUCH A BIG TOPIC AT THE MOMENT?

It all revolves around an organisation based in Jamaica called the International Seabed Authority, which was set up in the 1980s as the body to regulate deep-sea mining.

For a long time, not much really happened at the meetings of its 167 member states. But now we've had an artificial acceleration due to a loophole: some mining companies paired up with particular countries, forcing this agenda to be concluded more quickly than it might otherwise be. They're demanding to have regulations put in place so that mining can start happening within the next year.

At the time of writing, the latest round of meetings are concluding in Jamaica. And, for the first time, countries are listening to the scientists. So far, decisions on whether commercial mining will be allowed have been pushed back by at least two years. We need much more than that, but at least it seems there's not going to be an immediate rush to do this.

DR HELEN SCALES
Helen is a marine biologist and writer. She's the author of The Brilliant Abyss *(Bloomsbury), and her next book* What the Wild Sea Can Be *will be published in the summer of 2024.*

COMMENT

PALEO IS A FLINTSTONE FANTASY

'Big farmer' has changed our digestive capabilities... and that's just one of the reasons why you can't eat like a caveman

Most non-communicable diseases are diet-related, including obesity and its associated illnesses. Because the prevalence of obesity is a contemporary problem, some argue that our modern diet, based on agriculture, is to blame. This is the so-called 'paleo' movement.

'Paleo' is a contraction of Palaeolithic, the period from about 2.6 million years ago to 10,000 BC (the Stone Age). The paleo premise is that for most of human existence, we were hunter-gatherers. Then the agricultural revolution changed our diet and our current problems with diet-related illnesses occur because we haven't yet adapted to it. Hence the suggested solution of to return to a 'paleo diet'.

There are two main problems with this argument. First, there is no single paleo diet, because there were no singular Palaeolithic people – hunter-gatherers ate whatever was available to them. Second, the contention that humans haven't had time to adapt to an agricultural diet is simply incorrect, because when the right selection pressure is present, humans can adapt (and have) in just a few thousand years. Three examples of such adaptations are our ability to consume large amounts of starch, milk and alcohol.

Digestion of starch begins with amylase in saliva, which breaks down starch as we chew, and as the food moves to the stomach and small intestine, where other amylases from the pancreas and other organs take over. Although we typically carry two copies of most genes, one from each parent, humans have a variable number of the amylase-encoding gene AMY1, ranging from two to more than 30. The more AMY1, the better your ability to digest starch.

Genetic studies on hunter-gatherer peoples today, who subsist on high-protein/low-starch diets, reveal they have fewer copies of AMY1; while other primates, who mainly eat fruit, only ever have two.

Humans have always eaten starch, we were just unable to access all of the available calories. This wasn't a problem when starch wasn't our main source of calories, which it is today. This genetic adaptation improved our efficiency to metabolise starch, meaning we could eat less food and get the same number of calories. This increased nutritional efficiency provided a huge selective advantage, and was thus incorporated into gene-pool. As such, almost all humans today carry multiple copies of AMY1.

Then there's milk. All humans can drink milk in early life, but many then switch to being lactose intolerant as they begin adulthood. However, with the domestication of large ruminants, people began to realise that compared to simply eating the animals, drinking their milk greatly increased the calories available from each animal during its life. Couple this with the development of cheese, which allowed for the nutrients in milk to be preserved in compact and portable form and voilà: a new, rich and renewable food source was available to nascent herding communities.

So powerful was the selection pressure in herding societies that the ability to digest lactose as adults actually emerged independently at least three times: in northern Europe and in two geographically distinct African populations. The incredible thing is that although the adaptation in the three cases involved different genetic changes, they all influence the same gene, lactase, required for metabolising lactose into glucose. But lactose is lactose, no matter which type of milk it's found in. So, if you have the genetic adaptation to digest lactose as an adult, then milk, whether from human, cow, sheep or goat, isn't going to be bad for you.

Finally, the consumption of alcohol coincided with the emergence of agriculture, when humans began turning fermented fruit and other foods into alcoholic drinks. This influenced the way certain populations solved the problem of safe drinking water. Beer and wine, were used by those in the Fertile Crescent (today's Middle East) and northern Europe to ensure safe drinking water. In fact, European children drank weak beer up until the 17th century. Thus an enhanced ability to metabolise alcohol was a powerful selective advantage.

Other cultures, like East Asians, relied on boiling water instead. To be clear, ancient East Asians did drink alcohol (residue of the earliest known alcoholic beverage was found in a Neolithic Chinese village dating to 7,000-6,600 BC). But because East Asians had clean boiled water, they didn't have to drink alcohol, unlike Northern Europeans. Thus emerged the variation in the ability of different populations today to handle alcohol.

Ultimately, the paleo movement is a 'Flintstone' fantasy. The reality is that humans are like cockroaches, adapting when we have to, particularly to the selection pressure of changing nutritional demands post agriculture.

PROF GILES YEO
(@GilesYeo)
Giles is a professor of molecular neuroendocrinology at the University of Cambridge, and has presented Trust Me, I'm a Doctor *and episodes of* Horizon *on BBC Two.*

"The reality is humans are like cockroaches, adapting when we have to"

ILLUSTRATION: SINEM ERKAS

CONNECT

WHO'S AFRAID OF THE BIG BANG SINGULARITY?

The Big Bang marks the beginning of the Universe, right? The physicists brave enough to look beyond it aren't so sure

Why does something exist rather than nothing? This profound question lies at the heart of both science and philosophy, inviting us to explore the origins of our existence.

In the field of evolutionary theory, we understand that all life on Earth can be traced back to a common ancestor known as the last universal common ancestor (LUCA). The search for LUCA captivates researchers investigating the origin of life. Our curiosity doesn't end there, though. We can delve further into the origins of Earth itself, and the Universe around it.

From a cosmological perspective, we discover a breathtaking connection between the birth of stars, the formation of planets and the expansion of the Universe. The dance of cosmic creation unfolds through a delicate interplay between the Universe's expansion rate, the gravitational collapse of dark matter and the capture of hydrogen – the life-giving element necessary for star formation. Without this intricate cosmic choreography, life as we know it wouldn't have come into existence.

Thus, our cosmic origin story begins with a fundamental question: What was the origin of the expanding spacetime of the Universe?

The prevailing model of the expanding Universe is often referred to as Big Bang Cosmology. Coined by the English astronomer Fred Hoyle during a BBC Radio broadcast in March 1949, this theory suggests that all matter in the Universe originated from a colossal explosion at a specific time in the distant past.

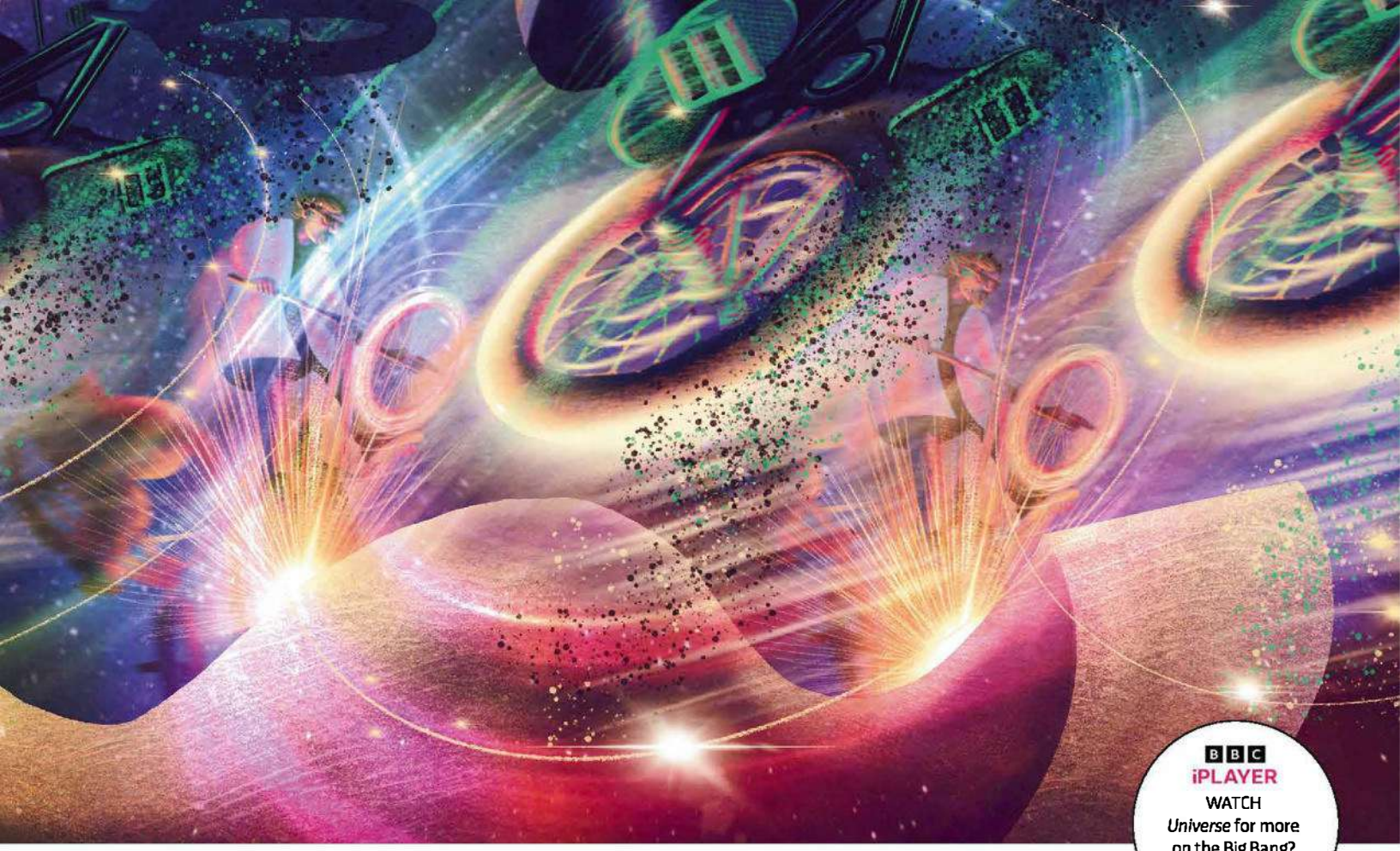
The idea of an expanding Universe is supported by Einstein's well-tested theory of general relativity, which portrays spacetime as a flexible medium capable of bending, expanding and collapsing. If we were to rewind the cosmic tape, we would witness the Universe contracting into an infinitesimally small point of infinite temperature, energy and spacetime curvature – an event known as the Big Bang singularity.

Stephen Hawking and his colleagues dedicated much of their careers to comprehending the perplexing nature of this singularity. After all, if everything, including time itself, came into being at the Big Bang, how can we discuss what transpired before time existed?

Fortunately, bold cosmologists have peered beyond the Big Bang singularity, seeking alternative explanations that transcend the conundrums of infinities and the origin of time.

One intriguing notion suggests that a cosmic epoch preceding the Big Bang gave rise to a new physics paradigm, effectively replacing the singularity. We know that Einstein's theory adheres to the principles of classical

ILLUSTRATION: MATT HOLLAND



BBC iPLAYER
WATCH *Universe* for more on the Big Bang? ***bit.ly/Universe BigBang***

"Fortunately, bold cosmologists have peered beyond the Big Bang singularity"

physics, so one plausible escape route involves the existence of a quantum 'bridge' connecting an expanding Universe to one that collapses into a Big Bang – an event commonly referred to as the Big Bounce.

Exploring this path requires extending Einstein's theory into the realm of quantum gravity, and both string theory and loop quantum gravity offer potential variants of the Big Bounce within the framework of quantum gravity.

In a previous column, I touched upon the paradigm of cosmic inflation – a period of rapid expansion that holds fascinating connections to such things as the cosmic microwave background and the origin of structure in the Universe. But mathematical theorems established by Hawking and Roger Penrose reveal that inflation fails to escape the initial singularities present in the Big Bang.

In fact, inflation itself succumbs to its very own Big Bang singularity!

One idea that captures my imagination is the concept of cyclic inflation – a framework that combines cosmic inflation with the notion of cyclic collapse and expansion, or bounces. This captivating idea, conceived by former postdoctoral researcher Dr Tirthabir Biswas and myself, suggests that the Universe undergoes infinite cycles of collapse and expansion.

After a critical cycle, with sufficient entropy accumulated, the Universe experiences a rapid acceleration of spacetime known as inflation. By incorporating cycles of bounces, cyclic inflation embraces the benefits of inflation while offering a potential escape from the Big Bang singularity.

With cosmologists unafraid to look beyond the confines of the Big Bang, a thrilling challenge lies before us: to identify observational predictions that differentiate between these competing models of the early Universe and our origins. These distinctive predictions hold the key to determining which model accurately describes the origins of our existence.

Personally, I find a tantalising hint in the fact that supermassive black holes seem to form too early to be accounted for by our current cosmological standard model. Perhaps a specific bouncing or cyclic model can elegantly explain this cosmic anomaly?

The further we go on this intellectual journey, the more the mysteries of our cosmic origins unfold, inviting us to delve deeper into the enigmatic tapestry of the Universe. With each discovery, we inch closer to unravelling the secrets that illuminate our existence and shed light on the timeless question: why is there something rather than nothing?

PROF STEPHON ALEXANDER
(@stephstern)
Stephon is a professor of physics at Brown University, an author and an accomplished jazz saxophonist.

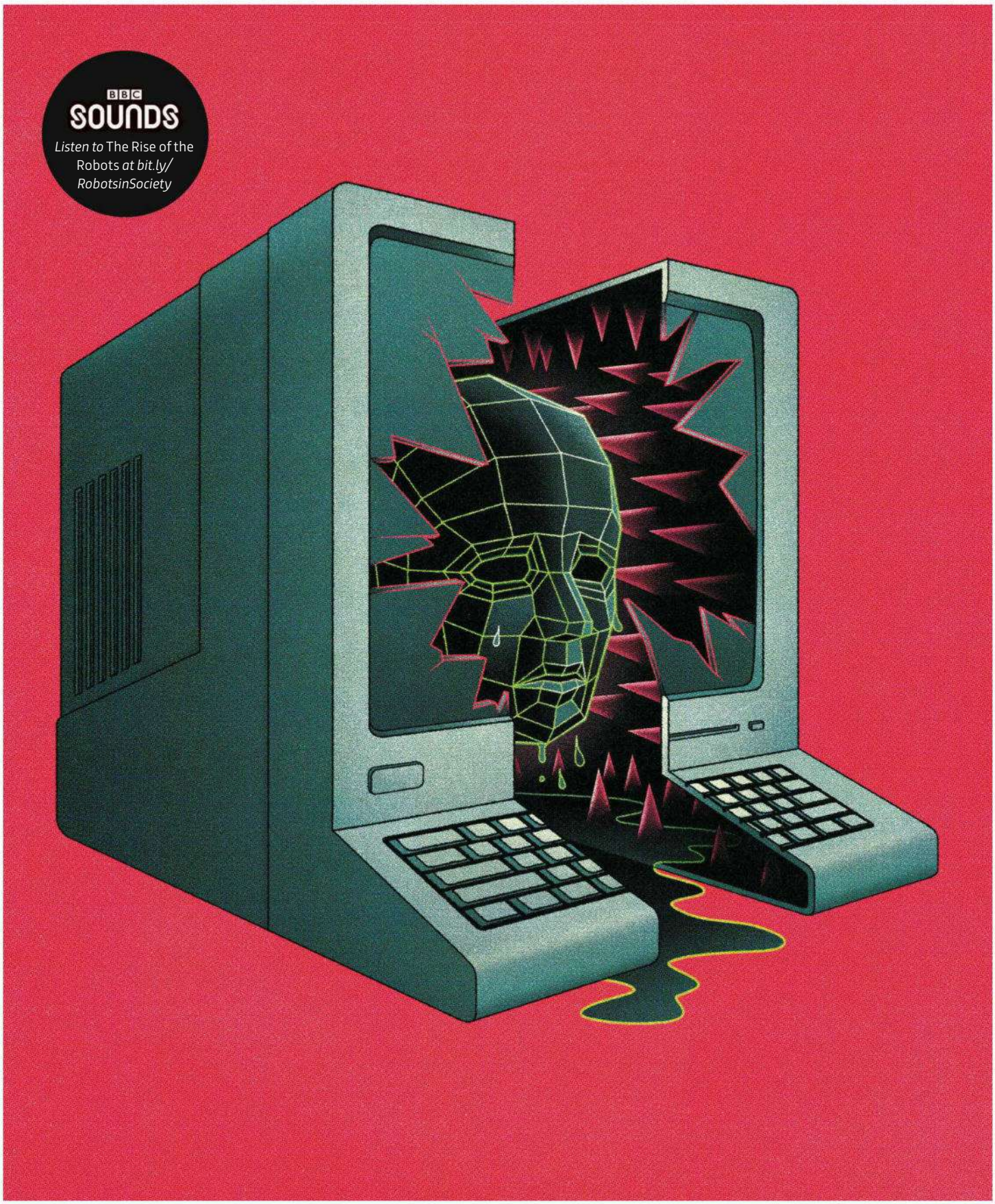


ILLUSTRATION: ADRIAN ARIAS ASTORGANO

COMMENT

DON'T KICK THE ROBOT

If something's got no feelings, you can't hurt it, right? So where's the harm?

A few years ago, someone asked me for advice on a workplace situation. His company was using a chatbot to help new employees and he had repeatedly noticed one person being disproportionally verbally abusive to it. "What do you think?" he asked me. "Is this an HR issue?"

The truth is, we don't know. But even though machines can't feel, it's worth thinking about what human behaviour is okay.

Over the next decade, our relationships to our devices will become a lot more interesting. Advanced chatbots and robot companions are on the rise, both extremely well-suited to tap into our social nature and make us behave as though we're interacting with something… alive. This raises the question: what does it mean to be verbally or physically violent toward an artificial agent?

People have already started to wonder. For example, during the mass adoption of virtual voice assistants, parents expressed concern that the little speakers in their living rooms were teaching their kids to be rude. Major companies such as Amazon and Google responded by releasing opt-in features that encouraged the use of 'please' and 'thank you', to prevent children from barking commands at the devices.

"People will readily treat any agent that moves like it's alive, even a randomly moving stick"

DR KATE DARLING
(@grok_)
Kate is a research scientist at the MIT Media Lab, studying human-robot interaction. Her book is The New Breed *(£20, Penguin).*

Of course, it's not the machines we're hurting, so the main concern is that 'mistreating' an artificial agent will lead to bad behaviour in other contexts. In 2015, my colleagues and I took a small step while investigating this idea, by finding a connection between people's empathic concern and how they were willing to treat a robot. Also, lots of research shows that people who witness violent behaviour toward a robot feel distress.

But even if there's a link between people's tendencies for empathy and how they feel toward a robot, that doesn't answer the question of whether beating up robots makes people more violent. Society has asked similar questions about porn and video games, with some inconclusive results. In many cases, people seem to do fine at compartmentalising (just because I play *Grand Theft Auto* doesn't mean I try to run people over in the car park at work).

Perhaps video games are mostly harmless, but does a robot with a body change the equation? We're physical creatures and studies show that we behave differently toward embodied robots than characters on a screen, in part because we're biologically hardwired to react to physical motion. People will readily treat any agent that moves like it's alive, even a randomly moving stick in a research study. As robot design gets better, the line between alive and lifelike may continue to blur in our subconscious minds.

If so, maybe it would be great for people to take out their aggression and frustration on human- and animal-like robots that mimic pain. After all, they aren't harming a living being, so it might be a healthy outlet for violent behaviour. On the other hand, it could be bad if it desensitises people to violence in other contexts. Would a child who grows up kicking a robot dog find it easier to kick a real dog?

Unfortunately, desensitisation remains a difficult thing to study. It's hard to connect long-term behaviour changes to an exact cause. Some limited research has tried to delve into the issue about robots and language-capable agents, but on the whole, we don't have a very solid answer.

The idea that being cruel to a robot could make us more cruel is akin to Immanuel Kant's philosophy regarding animal rights (which was not about protecting the animals themselves). But it's only a good argument if we have enough evidence to back it up. After all, if being cruel to robots doesn't actually turn people into sociopaths, there's less reason for concern. But maybe Kantian philosophy isn't the only way to think about the problem.

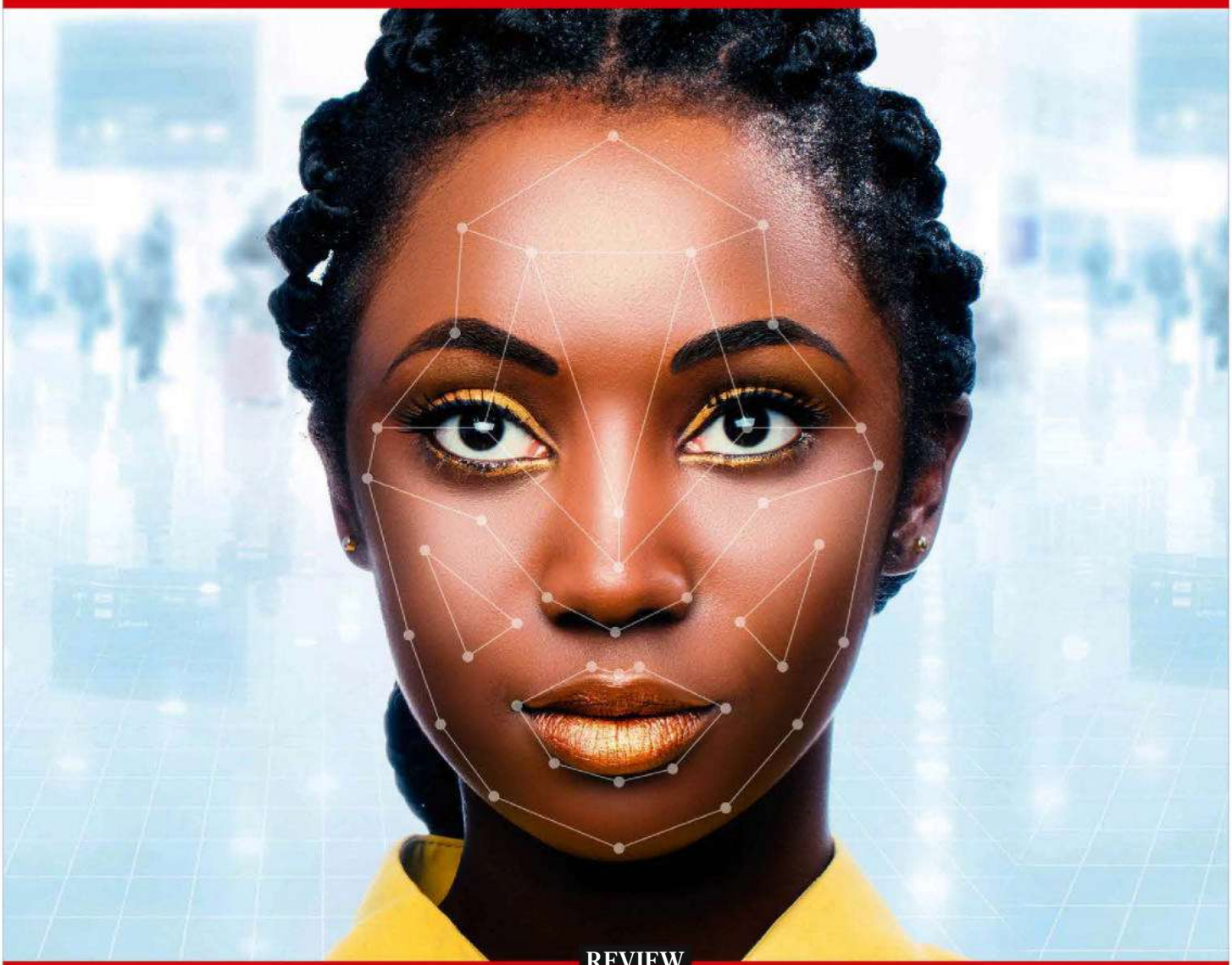
Philosopher Prof Shannon Vallor offers a slightly different approach in her book *Technology and the Virtues*: "From the perspective of virtue ethics, people who spend most of their free time […] torturing robots […] are not living well or flourishing, because they are not by this activity cultivating any of the character traits, skills or motivations that constitute human excellence and flourishing." Instead, she argues we should encourage activities that help people live out character traits we see as good and admirable.

For now, it seems pretty reasonable to keep robot abuse away from impressionable children, at least until we have more research on the effects of it. But even for the rest of us, maybe it's just not cool to treat an artificial agent poorly. Yes, it's much better than mistreating a living, breathing being, but why do it at all? As Vallor argues, it might be worth practising kindness, instead.

REALITY CHECK

THE SCIENCE BEHIND THE HEADLINES

Live facial recognition | Skin cancer | Hay fever



REVIEW

LIVE FACIAL RECOGNITION: THE MET POLICE'S CONTROVERSIAL NEW TECH

It has already been used at high-profile events, despite concerns about the privacy, accuracy and bias of this AI-driven system

"While the UK government is pushing for increased use of this AI surveillance tech, many other countries with the notable exception of China, are not"

BBC *Visit the BBC's* Reality Check *website at* ***bit.ly/reality_check_*** *or follow them on Twitter* ***@BBCRealityCheck***

Government ministers in the UK are pushing for the MET police to make use of automated facial recognition for routine law enforcement.

As police officers already wear body cameras, it would be possible to send the images they record directly to live facial recognition (LFR) systems. This would mean everyone the officers encounter could be instantly checked to see if they match the data of someone on a watchlist – a database of offenders wanted by the police and courts.

The technology has already been used for high-profile gatherings such as King Charles's Coronation, but could rolling it out more widely lead to a rise in distrust of the police force due to concerns about accuracy and privacy?

WHAT IS LFR AND HOW DOES IT WORK?

Artificial intelligences (AIs) trained to perform facial recognition were one of the first types of practical machine learning systems developed by computer scientists.

They're commonly used alongside 'dot projector' lasers, which can map thousands of points on a human face, to create the highly accurate biometric readers that we use to unlock our phones.

The LFR used by the police is much simpler. It relies on a camera to scan the surroundings and create a flat image. This image is then split into segments by the AI and the faces in it are mapped to find key features, such as distances between the eyes, noses and mouths, to build simple biometric records.

These records can then be compared to those stored in a database of known offenders using a neural network – a type of AI inspired by the human brain.

This method of using images alone is far less accurate than the laser-mapping method used by phones, however, as it doesn't consider the three-dimensional shape of faces.

It also relies on the neural network to be able to match faces correctly. The AI has to be trained on enough examples of faces to enable it to distinguish properly between them. If the data it was trained on is biased towards certain types of faces, then the AI will be biased in its ability to classify faces.

WHAT IS LFR USED FOR AND WHAT IS ITS LEGAL STANDING?

LFR has been used in England and Wales for a number of events including protests, concerts, the Notting Hill Carnival and Remembrance Sunday, as well as on busy shopping streets such as Oxford Street in London.

While the UK government is pushing for increased use of this AI surveillance tech, many other countries, with the notable exception of China, are not.

Back in October 2021, the European Parliament called for a ban on the use of LFR in public places. MEPs also asked for a ban on private facial recognition databases and supported an AI bill aiming to ban the type of social scoring systems used in China, where citizens are given a 'trustworthiness' rating based on their observed behaviour.

In the UK, the use of LFR has been successfully challenged in court by Liberty, while other civil liberty groups and the Information Commissioner's Office argue that the technology can infringe on privacy and data protection laws, and can also be discriminatory.

Liberty claims that because of their legal victory against South Wales Police, the use of this technology is unlawful in the UK as it "violates human rights, equality and →

ALAMY X2

BELOW Civil liberty groups argue that LFR scans people's faces without their consent, thereby violating their right to privacy

POLICE
LIVE FACIAL
RECOGNITION
IN OPERATION
Police officers are using Live Facial Recognition (LFR) technology to find people who are wanted by the police or the courts.
If you pass through the LFR system your facial biometric data will be processed.
There is no legal requirement for you to pass through the LFR system. If you do, then unless an alert is triggered, the system will immediately and automatically delete your biometric data.
For more information on LFR including the Met's privacy policy and how to exercise your data protection rights go to:
www.met.police.uk/FR
METROPOLITAN POLICE

ABOVE The Met Police notified people attending the recent Coronation that live facial recognition was being used

→ data protection laws". The UK government disputes this claim, however.

WHY IS IT CONTROVERSIAL?

There are two main reasons. The first is the argument that we should have the right to privacy. If cameras scan our faces and read our biometric data without our consent, then some argue that our rights are being infringed.

Proponents of LFR say that as the images are deleted immediately after being scanned, the benefits it offers are worth the minor loss of privacy.

But when the images used to train the AIs might have been scraped from the internet – including your social media – then it's harder to argue that data protection rights are being maintained.

The other important reason for the controversy is that LFR and similar technologies have previously been found to be inaccurate and biased.

Often the neural network trained to distinguish faces has been given biased data – typically the neural networks are trained on more male white faces than other races and genders.

Researchers have shown that while the accuracy of detecting white males is impressive, the biased training means that the AI is much less accurate when attempting to match female faces and faces of people of colour.

HOW COULD IT BE USED LESS INTRUSIVELY?

As LFR technology continues to develop, its accuracy will improve. This may mean that concerns of bias may one day disappear. But police training should make it clear that a face matching performed by LFR will never be as accurate as simpler technologies, such as ANPR (automatic numberplate recognition).

Also, to build trust, the use of LFR should be clearly displayed, and members of the public given the right to say they do not wish for it to be switched on if it violates their perceived privacy.

by **DR PETER BENTLEY**

Peter is a computer scientist and author who is based at University College London. His latest book 10 Short Lessons in Artificial Intelligence *is out now.*

ANALYSIS

SKIN CANCER: CASES ARE RISING. WHAT CAN WE DO?

Annual cases are expected to reach 2.7 million by 2040

Recent reports suggest skin cancer rates are rising. The harmful effects of the UV radiation in sunlight, and emitted by tanning beds, are well established – UV damages the DNA in skin cells, leading to errors as these cells replicate and grow.

But we've been warned for decades about the dangers of spending too much time in the sun or on sunbeds. So why is the message not sinking in?

While recent news has focused on the UK, Dr Zoë Venables, dermatology clinical lead at the National Disease Registration Service, confirms that the increase in diagnoses is more widespread than that.

"Across the UK and globally, skin cancer incidence is increasing in fair-skinned populations," she says.

Data published this year shows that, in the UK, over 224,000 people were diagnosed with skin cancer in 2019, an increase of more than a quarter compared to 2013, when there fewer than 178,000 new diagnoses.

These numbers include both melanoma, which affects the pigment-containing cells involved in tanning, as well as other, more treatable types of cancer affecting other cells in the outer layer (epidermis) of the skin.

It's worth noting that non-melanoma skin cancers, although less deadly, affect far more people and therefore still cause large numbers of deaths.

Globally, rates vary, but Eastern European countries are seeing some of the largest increases in melanoma. Meanwhile, there's some evidence to suggest that in Australia, which has traditionally had the worst rates, skin cancer cases are starting to plateau, with recent declines seen in under 40s.

But rates are expected to continue rising everywhere, with the International Agency for Research on Cancer predicting an increase from 1.5 million new skin cancer cases in 2020 to 2.7 million in 2040.

However, as Venables points out, it's difficult to predict the future. For example, we don't yet know what effect the increasing temperatures due to climate change will have. It's thought the rise in skin cancer rates that we're seeing now is related to changes in behaviour that started in the late 20th century.

"Cheaper access to foreign travel from the 1980s and our ageing population are likely to be contributing to increasing skin cancer incidence," she says.

ALAMY, GETTY IMAGES

"While the dangers of tanning may be well known, it seems not enough of us are following the advice to stay out of the sun"

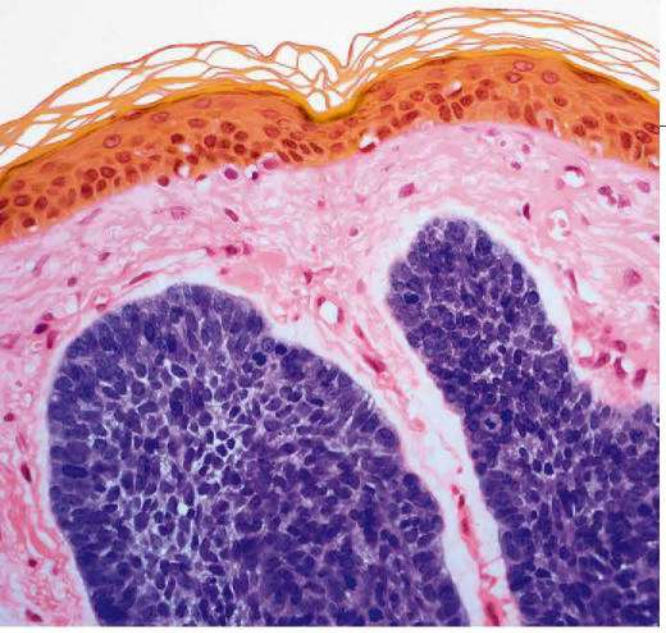
While the dangers of tanning may be well known, it seems not enough of us are following advice to stay out of the sun. As Dr Gernot Walko, a skin cancer expert at Queen Mary University of London, explains, even the levelling-off of skin cancer rates in Australia may have less to do with people changing their behaviour than with the population itself changing.

"Australia, historically, had a European population, with lots and lots of people matching the high-risk criteria of having fair skin, red hair, freckles and so on," he says. "Some scientists would argue that this is probably changing due to immigration."

ABOVE The more skin you expose to sunlight the more your risk of developing skin cancer increases

On the other hand, statistics on tanning beds show that their use has decreased, probably partly reflecting tighter restrictions on their use introduced in the late 2000s. In the five years to 2012, the proportion of adults using sunbeds was 18 per cent, on average. This figure dropped to 10 per cent over the next five years, while over the same period, the proportion of adolescents using sunbeds dropped from 22 to 7 per cent.

However, as skin cancer is the result of a lifetime of UV exposure, we won't know for a while how these decreases will affect diagnoses. Numerous studies have linked sunbed use to skin cancer, with those →



ABOVE The cells of a skin cancer tumour (in purple) seen under a microscope

→ who use sunbeds more regularly, for longer periods, or at a younger age, facing a higher risk.

So what can we do to lessen the risk? Advice on tanning and sunbeds may be well publicised, but it bears repeating. As the NHS notes, "there is no safe or healthy way to get a tan" – all sun damage contributes to skin cancer risk.

Walko adds that by middle age, most of us will have accumulated some of the mutations known to cause skin cancer, but scientists aren't sure what protects some people and not others from developing it.

We can look at public health messaging and conclude that we just need to cover up. But it's not that straightforward – changing behaviour means changing attitudes.

It also means we need to stop idealising and glamorising tanned bodies. Take *Love Island*, says Walko: "If we see good-looking people tanning and running around in swimsuits, it doesn't necessarily help with that societal image that we need to have a tan to look good."

Meanwhile, dispelling some of the myths that keep people running back to the sunbeds couldn't hurt. A 2022 study, for instance, drew attention to a couple of ill-conceived notions.

One, for example, is that artificial tanning can help with acne. But it's actually red and blue light (containing no UV radiation) that are sometimes incorporated into acne treatments. Another is that sunbeds prepare the skin for sun exposure on holiday.

Governments could also do more. In 2010, the UK took the step of banning sunbeds for under 18s, but across the US and Europe, regulations and age restrictions differ. In some US states, it's a matter of parental consent rather than an outright ban. Australia, by comparison, has outlawed sunbeds entirely.

by **HAYLEY BENNETT** *(@gingerbreadlady)*
Hayley Bennett is a science writer based in Bristol, UK.

COMMENT

HAY FEVER: IS IT REALLY GETTING WORSE?

Hay fever sufferers say their allergies are getting worse... and climate change could be to blame

Earlier this year the Met Office warned that hay fever could get worse due to climate change. And it's not just a hypothetical problem we may face in the future. In a recent paper, researchers dug into pollen trends over the last 26 years across the UK, focussing on grass, birch and oak pollen, to investigate how changing weather patterns are already affecting hay fever season.

While the work showed that climate change is certainly having an effect, the exact changes depend on which kind of pollen you're affected by. The season for birch pollen (the second most important type when it comes to hay fever, after grass pollen), is increasing in severity – meaning the total amount of pollen seen during the season is higher.

Oak pollen season is also starting earlier and lasting longer. But there's some good news regarding grass pollen: while the first day with high grass pollen levels seems to be getting earlier, the season doesn't appear to be getting worse.

The data in the study only goes as far as 2020, but Dr Beverly Adams-Groom, lead author of the paper and senior palynologist at the University of Worcester, says those trends appear to be continuing.

"The birch pollen season this year and in 2021 were among the very worst that we've ever seen," she says.

Pollen is a fine powder made by plants as part of their reproductive cycle and hay fever is an allergic reaction to proteins found on the pollen when it gets into our eyes, nose and throat.

In the UK there are three main hay fever seasons caused, respectively, by tree pollen, which starts in March and lasts until mid-May; grass pollen, which typically lasts from mid-May to July; and weed pollen, which runs from the end of June until September.

When it comes to climate change, higher levels of carbon dioxide in the atmosphere and warmer temperatures should, in theory, stimulate plant growth, meaning plants can grow faster, flower earlier and make more pollen.

A European team of researchers has shown that grass pollen season in countries including the UK could get much worse if we don't significantly rein in the amount of carbon dioxide we're releasing into the atmosphere. They predict that the amount of grass

SCIENCE PHOTO LIBRARY, GETTY IMAGES

> “Despite the fact that the amount of pollen itself isn’t increasing, the potency [of the allergens] might be”

ABOVE
The catkins that dangle from the branches of birch trees release clouds of fine pollen when disturbed

pollen could increase by up to 60 per cent if carbon dioxide levels were to double.

In reality, however, the specific effects will be complicated by the changing weather patterns we’re already seeing due to climate change.

In the UK we’re experiencing warmer, wetter winters; hotter, drier summers; and more frequent and intense weather extremes. Both the weather conditions when a plant is producing pollen, and the conditions when it releases that pollen, play a part in determining how much reaches the eyes and noses of hay fever sufferers in any given year.

Higher temperatures and more hours of sunshine earlier in the year are driving the increase in oak pollen seen in recent years. Rising temperatures are also making birch pollen season worse. “Birch pollen production usually occurs in June of the previous summer, and it’s released in April,” says Adams-Groom.

If we have warm weather in the summer, then tree pollen season the following year is likely to be more severe. But exactly how bad it ends up being depends on the weather that next year, too.

“We need to have good weather in-season for the pollen to actually be dispersed,” says Adams-Groom. “If it’s raining all the time, if it’s cold, then the pollen grains will remain within the flowers.”

Grasses produce their pollen closer to when they release it. A sustained number of warm, dry days during grass pollen season (such as during the hottest June on record) can result in a lot of high pollen days in a row, but then lead to grasses quickly depleting themselves and a season that ends earlier than usual.

But drier weather earlier in spring can mean grasses don’t produce as much pollen as usual.

To complicate things further, it’s possible that the pollen count doesn’t give us a full picture of how bad someone’s hay fever symptoms are likely to be on any given day. There could be other factors behind anecdotal reports that hay fever seasons are getting tougher, Adams-Groom suggests.

Other emerging research shows that factors including carbon dioxide and air pollution can increase the potency of pollen grains, meaning that even if the amount of pollen in the air isn’t increasing – and the season overall isn’t getting more severe – each pollen grain could be carrying more of the allergenic protein that causes hay fever symptoms.

“We can’t be sure exactly what’s going on,” says Adams-Groom. “But we have to assume that, possibly, despite the fact that the amount of pollen itself isn’t increasing in the atmosphere, that the potency [of the allergens] might be.”

All of this adds up to the potential for hay fever seasons to get worse with climate change. But, much like trying to predict the weather, the devil will be in the details. So we’ll have to wait for each hay fever season to arrive before we truly know how bad (or not) it’s going to be. **SF**

by KELLY OAKES (@kahoakes)
Kelly is a science writer who covers science, technology, health and the environment.

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INNOVATIONS

PREPARE YOURSELF FOR TOMORROW

ANALYSIS

AI DISCOVERS NEW DRUGS

New anti-ageing medication identified in minutes with machine learning **p40**

NEW TECH

IDEAS WE LIKE

Our pick of this month's greatest new gadgets **p44**

REVIEW

BARBECUES

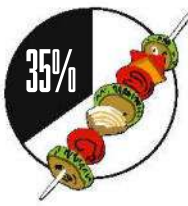
Flame on! The *BBC Science Focus* team finds their favourite outdoor grills **p42**

Cook up a storm with a high-tech outdoor oven p42

THREE OUT OF FOUR HOMES IN THE UK OWNS A BARBECUE

£258,000,000

THE ANNUAL AMOUNT SPENT ON BARBECUES IN THE UK



THE PERCENTAGE OF BARBECUES IN 2022 THAT WERE ENTIRELY VEGAN

PDF NEWSPAPERS and MAGAZINES: WWW.XSAVA.XYZ

ANALYSIS

Artificial intelligence discovers drugs to fight ageing

Researchers at the University of Edinburgh use machine learning algorithm to identify drugs with potential new applications in minutes

Artificial intelligence (AI) has been the driving force behind a lot of big developments in the last year. But while super-intelligent chatbots and rapid art generation have gripped the internet, elsewhere AI has been used to try and find solutions to one of humanity's biggest problems: ageing.

Researchers at the University of Edinburgh, working in the field of drug discovery, have used machine-learning systems to unearth a selection of new anti-ageing drugs.

Machine learning is a branch of AI that focuses on using data to imitate the way that humans learn, improving its accuracy as its fed more data. In the past, machine learning has been used to create chess-playing robots, self-driving cars and even Netflix recommendations, but in this case the algorithm was looking for senolytics.

Senolytics are drugs that are able to slow ageing, as well as prevent age-related diseases. They work by killing off senescent cells, which, although still alive, are no longer able to replicate. While having cells that don't replicate isn't necessarily a bad thing, they will have suffered damage to their DNA (sunburned skin cells, for example), so stopping replication stops the damage from spreading.

Vanessa Smer-Barreto, a research fellow at the University of Edinburgh's Institute of Genetics and Molecular Medicine, was investigating new drugs, specifically senolytics, in her post-doctorate research.

Frustrated by the expense and time involved in the process of drug discovery, she turned to machine learning in the hopes of reducing both.

"Generating your own biological data can be really expensive, and it can take a lot of time, even just to gather training data," she says.

"What made our approach different to others is that we tried to do it on limited funds. We took training data from existing literature and looked into how to use this with machine learning to speed things up."

By using a machine learning algorithm, she was able to find three promising senolytics.

UNMISTAKABLE EXAMPLES

Smer-Barreto and her colleagues fed an AI model with examples of known senolytics and non-senolytics, teaching it to distinguish between the two. The AI could then be used to predict whether molecules it hadn't seen before could be senolytics based on whether or not they matched the examples it had been given.

Around 80 senolytics are known, but of that number, just two have been tested on humans. While that sounds like a tiny percentage, bear in mind that it takes 10 to 20 years for drugs to reach the market, along with huge funds.

The team started by reading through a wide range of papers, but were selective with the results, limiting themselves to just

Vanessa Smer-Barreto was part of the team that identified three new senolytics using machine learning

Machine learning has the potential to identify new drugs for a number of conditions

GETTY IMAGES, UNIVERSITY OF EDINBURGH

"THERE IS NOTHING TO STOP US FROM APPLYING SIMILAR TECHNIQUES TOWARDS OTHER DISEASES SUCH AS CANCER"

58 of the 80 known senolytic compounds. By doing this, they cut out any compounds that weren't clearly senolytics.

A total of 4,340 molecules were then fed into the machine-learning model, which returned a list of results just five minutes later. The model had identified 21 molecules that it deemed likely to be senolytics. Without the machine-learning model, this process could have taken weeks and huge sums of money.

Finally, the 21 potential senolytics were tested on two types of cells: healthy and ageing.

Of the 21 potential candidates, there were three able to eliminate the ageing cells, while still keeping normal cells alive. These new senolytics have been put forward for further testing to understand more about the way they interact with the body.

DISCOVERY IS JUST THE BEGINNING

While the study was successful, it's just the start for this research. "The next step is to team up with clinicians at the University of Edinburgh to try testing the senolytics we discovered on their samples of robust human lung tissue," Smer-Baretto says.

Through these future tests on lung tissue, the team hopes to see whether the newly identified senolytics can fight ageing on tissue from damaged organs. But Smer-Baretto points out that no patients are going to be given a big dose of the potential new drugs, especially in these early stages. These drugs will be tested on tissue models first and only after that testing phase is completed could they possibly be administered to people, and even then it'll be in the form of micro-doses.

"I have seen some criticism about the toxicity of the drugs. It's essential that with any drug we're administering – or experimenting with – that we consider the fact that it may do more harm than good," says Smer-Baretto.

"The most powerful drug we found is called oleandrin. There is some criticism about it being toxic, but we discuss this in the original scientific publication. The drugs have to go through many stages of testing first, and if they make it to the market, they'll have gone through a host of safety tests."

While in this instance machine learning was searching for drugs related to ageing, there's nothing stopping these algorithms being trained to identify potential drugs for other conditions.

"We had a very specific approach, but there is nothing stopping us from applying similar techniques towards other diseases, such as cancer. We're keen to explore all avenues."

If there is enough available data, AI models can rapidly accelerate the process of drug discovery, as well as reducing the costs required for it, across a wide range of diseases including cancer.

Five of the best BBQs for the summer

There are hundreds of BBQs on the market, all boasting their own impressive features. But which is the best? The *BBC Science Focus* team picks their faves...

Kamado Joe Classic Joe Grill Series III

international.kamadojoe.com, £2,149

This is the Rolls Royce of barbecues, and it's all thanks to its ceramic shell. Once the ceramic gets hot it needs little energy to stay that way, so once you've lit your charcoal and heated the barbecue to the desired temperature (indicated by the thermometer on the front) it'll stay there.

If you want to slow or speed up the cook, you simply change the airflow by opening or shutting the vents at the top and bottom. This lends the entire practice of cooking outside a degree of predictability, hence why professional chefs love these cookers.

The Kamado excels at slow cooking things like beef brisket or a lamb shoulder, where a long, gentle cook is vital for good results. It'll also go low and slow enough to allow you to reverse sear a steak, but it's equally good if you just want to throw a rib-eye on the coals. Plus, the even heat output means cooking veg or side dishes on pans or baskets is easy. It's our ultimate choice for a barbecue, but has an eye-watering price to match.

Gozney Dome

gozney.com, £1,799

This is one of the most desirable outdoor ovens going and it delivers on the hype. The model we tested can use either wood or gas as fuel, and comes with a vital internal thermometer so you can get to grips with how it heats up.

500°C (900°F) is the goal. It's the temperature where the magic happens when it comes to pizza, meat and veg. It singes and sears the outside of whatever you're cooking, while keeping the inside moist. Vegetables roast, sweeten and retain their bite; bread puffs, crisps and chars; while meat sizzles, crackles and forms all the crispy bits that make you sigh when you bite in and start chewing.

Other pizza ovens can reach this temp of course, but the joy of the Dome is in it's form. The opening is big enough to throw pans, roasting dishes and bread trays in or manipulate pizzas as needed.

The internal thermometer takes away a lot of the guessing, and the functional stand makes juggling food a breeze. You'll need some accessories, like a pizza paddle, a door (if you want to slow cook) and a wood loader (if you want to avoid toasting your hair). It's expensive, but great for those who consider cooking outside a way of life.

Ninja Woodfire Electric BBQ Grill & Smoker

ninjakitchen.co.uk, £349

The Ninja Woodfire has a lot going on, but that's by no means a complaint. In fact, it's what makes this such a good product. Yes, it's a barbecue, but it's also a smoker and air fryer. It lets you smoothly transition from air frying some golden potatoes to smoking a pork belly, before finishing up with some perfectly cooked burgers on the grill. It's the Iron Man of the barbecue world, complete with buttons, gizmos and even a smoking chamber on the side.

The bad news is that all this tech makes for a heavy unit. That paired with the need to plug it in makes using it a bit of an ordeal. It's not the barbecue for the family camping trip, but more something for a meat-obsessed family member looking to spend eight hours slow cooking the perfect lamb with all the trimmings.

Ooni Koda 12

Ooni.com, £349

The Ooni Koda 12 is a fun, no-fuss, gas-powered pizza oven. Its simple design, rapid preheating capabilities and powerful heat output means you can get on with the really important stuff: eating.

It's gas-powered, so can reach temperatures of up to 500°C (900°F) in just quarter of an hour, allowing you to cook mouth-watering Neapolitan-style pizzas in a matter of minutes. They really are *good* pizzas, too – think crispy crusts with a soft dough and bubbling, gooey toppings.

Pizzas take just 60 seconds to cook, although we found that cooking them for slightly longer (around four minutes) on a slightly lower heat (around 410°C/770°F) while turning the pizza every 20-30 seconds or so, produced a more satisfying crust and base.

At 9.25kg (20lbs) it's also lightweight and portable. The legs even fold away for convenient transportation and storage.

Weber Go-Anywhere Charcoal Barbecue

Weber.com, £111.99

We're in love with the Weber Go-Anywhere. You can use every inch of its rectangular grilling space efficiently, but it's small enough to fit in tight spaces and store away easily.

What's more, it really can go anywhere. At just under 7kg (15lbs) and with the dimensions of a chunky backpack, you can easily pop it in your car. Or, if you fancy a light workout, you can walk it to your barbecue destination, as its nifty stand doubles as a clamp to hold it all together.

It's clean and classy, heats up quickly, and stays hot – and all for an affordable price. Finding faults isn't easy, but this is not the barbecue for you if you're catering for large gatherings: you may find it a struggle to cook for more than eight people in one go. But if we're not being silly about this, the Weber Go-Anywhere is a five-star no-brainer.

Ideas we like...

Our pick of the month's smartest tech

→

....A go-anywhere action camera

There is a ludicrous amount of action cameras available these days, all of which do roughly the same thing. So when something unique comes along, its worth shouting about it. Insta360 is claiming that its new Go 3 is the world's smallest action camera (fine, but so far, so familiar). What makes the Go 3 stand out is that it uses a range of magnetic mounts to let you quickly and easily attach it to... well, almost anything, anywhere. Chuck it on a bike, a car, a skateboard, a shirt, a wall or wherever you else you want and get filming. It's waterproof, captures 2.7K footage and can create 360° videos to get full coverage as you skydive, surf or just simply vlog your daily life.

Insta360 Go 3
Store.insta360.com, £379.99

...A head-up display for bikers

There have been many attempts at making smart glasses and most of them try to solve problems that really don't exist. But every so often a pair comes along that we can get behind. BMW's ConnectedRide Smartglasses are intended for motorcyclists and keep things simple. Wear them on a bike and you'll get a head-up display showing speed and navigation info. They're slim, so as to fit under a bike helmet, and by displaying minimal information, aren't enough to distract from the road. It all sounds great in theory, but like all smart glasses, they'll need to be proven in the real world first.

BMW Motorrad ConnectedRide
bmw-motorrad.co.uk, £TBC

...A home theatre to take on the go

The description for the Sony HT-AX7 speaker reads unlike any other equivalent device. This new gadget from the audio giant is a portable speaker, but also a surround sound home theatre. It's full of features, pumps out plenty of sound and has a 30-hour battery life, but only costs £499. It comes in three parts: one larger speaker and two smaller ones that sit on top, charging when not in use. Spreading the trio around a room, or whatever space you're in, gives you a simple spatial audio system that adapts to wherever you may be.

Sony HT-AX7
Sony.co.uk, £499

...A new version of Nothing

Last year's Nothing Phone was a new and extraordinary device that used a strange array of lights scattered across its back to discreetly display notifications. But while it was interesting, it was flawed and really quite basic. Now, the new Nothing Phone (2) has arrived, offering vast improvements over its predecessor. The 'Glyph' lights on the back can now be customised to display your own choice of flashes for every app, phone contact and notification. The lights can even be used as timers, battery life indicators and volume checkers. In a world of identical smartphones, this is a feature that sets the Nothing apart from the crowd.

Nothing Phone (2)
Nothing.tech, from £579

...A dictaphone for design nerds

Teenage Engineering appears to have found a direct link to the brains of the design obsessed, repeatedly making products that have them handing over vast amounts of cash for devices that can be had in app form on a smartphone. Their products are sleek, undeniably cool and... well, really expensive, and the TP-7 is no different. It's a palm-sized field recorder that's light on features, but is focused on intuitive design, high-quality audio recording, and an easy uploading and transcribing process. Are there cheaper options available? Yes, but none of them will make you feel like an old-school reporter quite like this.

Teenage Engineering TP-7
teenage.engineering, £1,299

IDEAS WE DON'T LIKE...

...A ROBOT DOG THAT HAS A FLAME-THROWER

What with everything going on in the world right now, it's no surprise that you can legally purchase a flame-throwing robot dog online. The real question is, should you? Throwflame is a company that specialises in attaching flamethrowers to things, having so far mounted them on drones, robots and people's backs. The Thermonator is the latest option, which Throwflame claims is the 'first-ever flamethrowing quadruped robot dog'. Little information is given on how it works, or how to use it, just a video of said robot dog trotting around a burning park... so nothing to worry about there.

Thermonator flame-throwing robot dog
throwflame.com, £TBC

...A FULLY LOADED E-BIKE

When the Urtopia team came to design its e-bike, we imagine a meeting took place to decide what features it should have and one of them piped up with, "Why choose? Let's just include everything." That might explain why it has a Bluetooth speaker, a smart voice assistant, a feature-packed app, a gaming-style controller on the bars to change settings and even a fingerprint-reading lock. This e-bike is equal parts innovative and headache-inducing. You'll either love it (for its power-assisted pedalling) or hate it (for having to ask it to turn on its voice-activated lights).

Urtopia Carbon One
global.newsurtopia.com, €3,299

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IN THIS ISSUE
Health
Environment
Nature
OBSESSION
EARTH'S MYSTERIOUS CORE
TIRED ALL THE TIME?
THE SECRET LIFE OF DOGS

S
4K

AHH

by DR BRITTNEY G BOROWIEC

ALAMY

EVERY LIVING THING HAS TO EAT SOMEHOW... WHATEVER TYPE OF MOUTH IT MIGHT HAVE. AND THERE ARE SOME TRULY BIZARRE MOUTHS IN THE ANIMAL KINGDOM. SOME OF THE MOST EXTRAORDINARY EXAMPLES ARE ENOUGH TO LEAVE YOU SLACK-JAWED

CAT GOT YOUR TONGUE?

PENGUIN

Penguins are agile predators underwater, zipping around like torpedoes as they chase down fish and squid. But how do they keep their prey from squirming out of their grasp? The answer lies in what the birds already have in their mouths.

A penguin's mouth and tongue are covered in hard, backward-pointing spines called papillae. It's the same feature that makes a cat's tongue feel like sandpaper. But you wouldn't want a penguin to lick you – the spines aren't just large, they're also sharp (a lick from one of these would easily make you bleed). The spines dig into slippery prey and help move it down the bird's throat.

A penguin's tongue is also very muscular, so is probably used to push and manipulate the food in their mouths, like humans. Unlike us, however, penguins can't taste the fish they eat, as they don't have the genes to register sweet, bitter or savoury (umani) flavours. Scientists think that penguins lost their sense of taste because they don't use it: not only do they swallow their food whole, but the proteins needed to send taste signals to the brain malfunction at cold temperatures.

→

BOTTOM FEEDER

SEA URCHIN

A sea urchin's mouth is on its underside, and that's probably the least bizarre thing about how it eats.

Inside the sea urchin is a complex, pyramid-shaped structure made of calcium carbonate, a hard chalky material also found in coral. The pyramid is made of several triangle-shaped plates, each with a hook-shaped tooth at the tip.

Like a claw machine you might find at an old arcade, the pyramid can move up and down, and tilt. It can also move each plate to scrape, grasp, burrow and even grind rocks. The individual plates are sharpened as they slide against each other, so they're always ready to cut. The whole apparatus is precisely controlled by a network of wiry muscles. Aided by their powerful jaws, sea urchins feed voraciously – a single colony of these spiky relatives of sea stars can destroy an entire kelp forest by chewing up rocks and uprooting seaweed.

The urchin's biological claw machine, properly called Aristotle's lantern, is so unique that it's inspiring engineers to design new machines to scoop up soil samples on Mars.

←

RAPID INFLATION

GULPER EEL

Food is scarce in the deep ocean, so animals living down there have to make every meal count. Few animals take this as seriously as the gulper eel, which is also known as the pelican eel as it shares a similar characteristic with the bird.

The gulper eel has a huge, loose-hinged mouth that's about a quarter of the length of its body. The mouth is paper-thin, fragile and unwieldy, so the eel tucks it away when it's not feeding.

Gulper eels have long, whip-like tails, but aren't fast enough to chase down their prey. Instead, they float and wait, camouflaged by the darkness of the deep ocean. When a school of crustaceans or squid approaches, the eel lunges forward, rapidly unfolding its origami mouth to take a huge gulp of water.

After the attack, with its mouth fully inflated, the eel looks silly, like a lollypop or a balloon. It then slowly pushes the extra water out through its gills before swallowing the unlucky prey trapped in this signature feature.

↑

THE ULTIMATE UNDERBITE

COOKIECUTTER SHARK

Back in the 1970s, several submarines belonging to the US Navy returned from missions with damaged sonar equipment. Initial fears of a new enemy weapon dissipated once the culprit was identified: the cookiecutter shark.

Cookiecutter sharks, as their name suggests, leave perfectly round cut-outs in large fish and marine mammals (and the rubber covers on subs' sonar domes). These parasites make their living through stealth and subterfuge, hovering in the water until a something big and tasty approaches. They sneak up and latch on with their fat, fleshy sucker lips. The sharks anchor themselves into place by digging in with their narrow upper teeth while the razor-sharp teeth in their lower jaws slice into the flesh. They twist and spin, moving their lower jaws back and forth like a bandsaw, carving out a perfectly round disc of meat before slinking back into the gloom of the deep sea.

Cookiecutter sharks are harmless to humans and little more than a pest to their huge prey, but still pose an occasional nuisance to ocean operations by damaging unprotected equipment and telecommunications cables.

NORBERT WU/NATUREPL.COM, SERGIO HANQUET/NATUREPL.COM, NOAA PICTURE LIBRARY

↓

UNFUSSY EATER

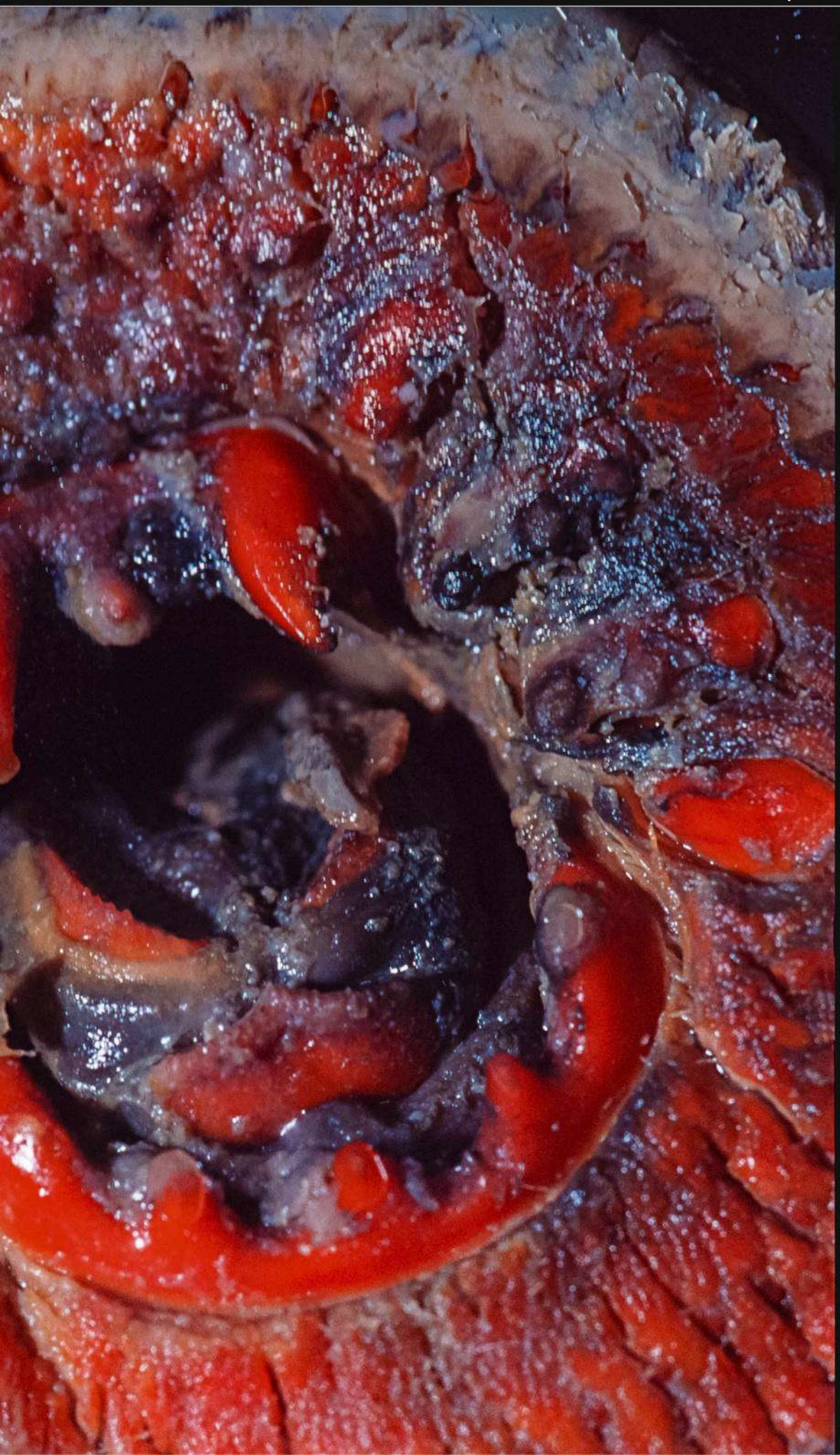
STRIPED MACKEREL

Most animals are relatively picky eaters, preferring only plants or only meat, and tend to rely on one strategy when foraging or hunting. Mackerel are unusual because they use two different ways of feeding, filter feeding and particulate feeding, and opportunistically switch between them whenever it makes sense.

Particulate feeding involves catching each prey item individually, like a shark or penguin would. Filter feeding is how bivalves and baleen whales eat and involves straining pieces of food out of the water. Mackerel use the underside their gills, which have overlapping bony hooks called gill rakers, as makeshift sieves to capture prey suspended in the water. All fish have gill rakers and variation in their appearance is sometimes used to identify different species.

When prey is small and numerous, like a swarm of plankton, filter feeding gets the most food for the least effort. For large or sparse prey, particulate feeding is better. By not being too picky about how they get their meals, individual mackerel keep their bellies full, even when surrounded by thousands of other fish in a school.

ALEX MUSTARD/NATUREPL.COM, DAVID KEARNES/BLUE PLANET ARCHIVE



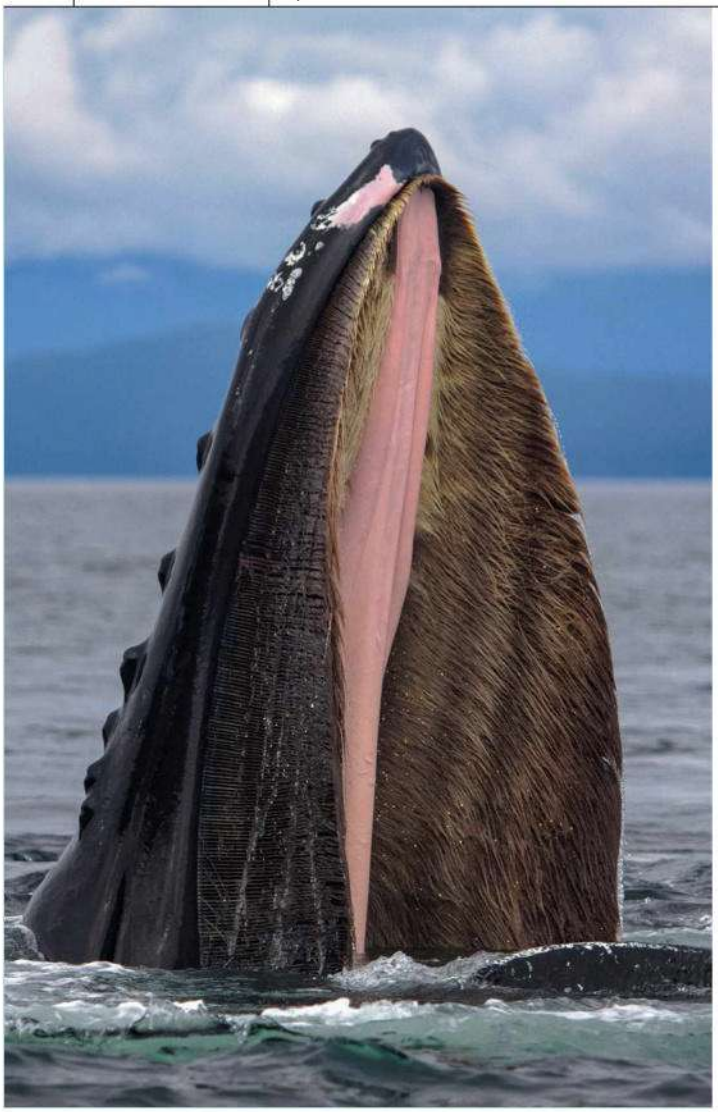
MONSTER MOUTH

LAMPREY

Several Hollywood creatures, including the sandworms from *Dune*, the kraken in *Pirates of the Caribbean* and the sarlacc from *Return of the Jedi*, have a stylised version of a lamprey's mouth. There's something extremely unsettling about concentric rings of sharp teeth leading into the black depths of a monster's throat.

Real-life lampreys are evolutionarily ancient animals that split off from the rest of the vertebrates over 500 million years ago – before the evolution of jaws and bone. Using a combination of suction and hooks made of keratin (the protein your fingernails are made from), a lamprey can latch onto large fish, whales or even sharks. Over the course of a few days, the lamprey burrows into its victim's flesh with a sharp, rasping tongue that works like a piston, engorging itself on blood and fluids.

The frightening appearance and unsavoury lifestyle of lampreys gives them a bad reputation. In reality, they're important members of the ecosystem: lamprey larvae filter water and sediment in rivers, like bivalves, and are an important food source for bottom-feeding predators, such as sturgeon.



PLATEFULS OF FOOD

HUMPBACK WHALE

Humpbacks only eat from spring to autumn during their holidays in the prey-rich waters of the Arctic and Antarctic. With such big bellies to fill and a limited time to do it, they rely on an ingenious strategy known as 'bubble-net hunting' to get the job done.

Often working in a group, humpbacks dive below their prey, then slowly ascend towards the surface in a spiral, blowing bubbles as they swim up. The bubbles scare and confuse their prey of small fish and shrimp-like crustaceans called krill. The whales make tighter and tighter turns, aided by their long flippers, concentrating their future meal into a dense cluster near the surface.

Eventually, they take turns lunging up, mouths open, through the compacted prey, gulping tens of thousands of litres in a single mouthful. The whales push the water out of their mouths, filtering it through the sieve-like baleen plates on the roofs of their mouths. The fish or krill are trapped in the strong but flexible bristles, ready to be swallowed whole by the hunters.

SAW THROAT

LEATHERBACK TURTLE

Leatherback turtles spend most of their lives in the open ocean, tracking their prey into the depths during the day and into the shallows at night. They're always looking for jellyfish, their favourite food, though they'll occasionally snack on other soft treats, such as squids or small crustaceans. Leatherback turtles eat so much jellyfish – hundreds of kilograms per turtle per day – that they act like natural pest control, keeping jellyfish populations in check and protecting larval fish and beaches from nuisance swarms.

Jellyfish are squishy and not the easiest thing to pin down, especially if you don't have any teeth or claws. Leatherback turtles snip jellyfish into digestible pieces with delicate, scissor-like jaws. What's more, the throat of a leatherback turtle is lined with backwards-pointing spines, which stop its slippery prey from escaping once caught (jellyfish can survive being cut in half, after all). The spikes probably also provide some protection from the stinging cells of their prey, as leatherback turtles can even eat poisonous creatures such as the jellyfish-like Portuguese man o' war with no ill effect.

JOHN CORNFORTH/BLUE PLANET ARCHIVE, TUI DE ROY/NATUREPL.COM, GETTY IMAGES, MDOMINGOA/WIKIPEDIA

↑

NUTCRACKER

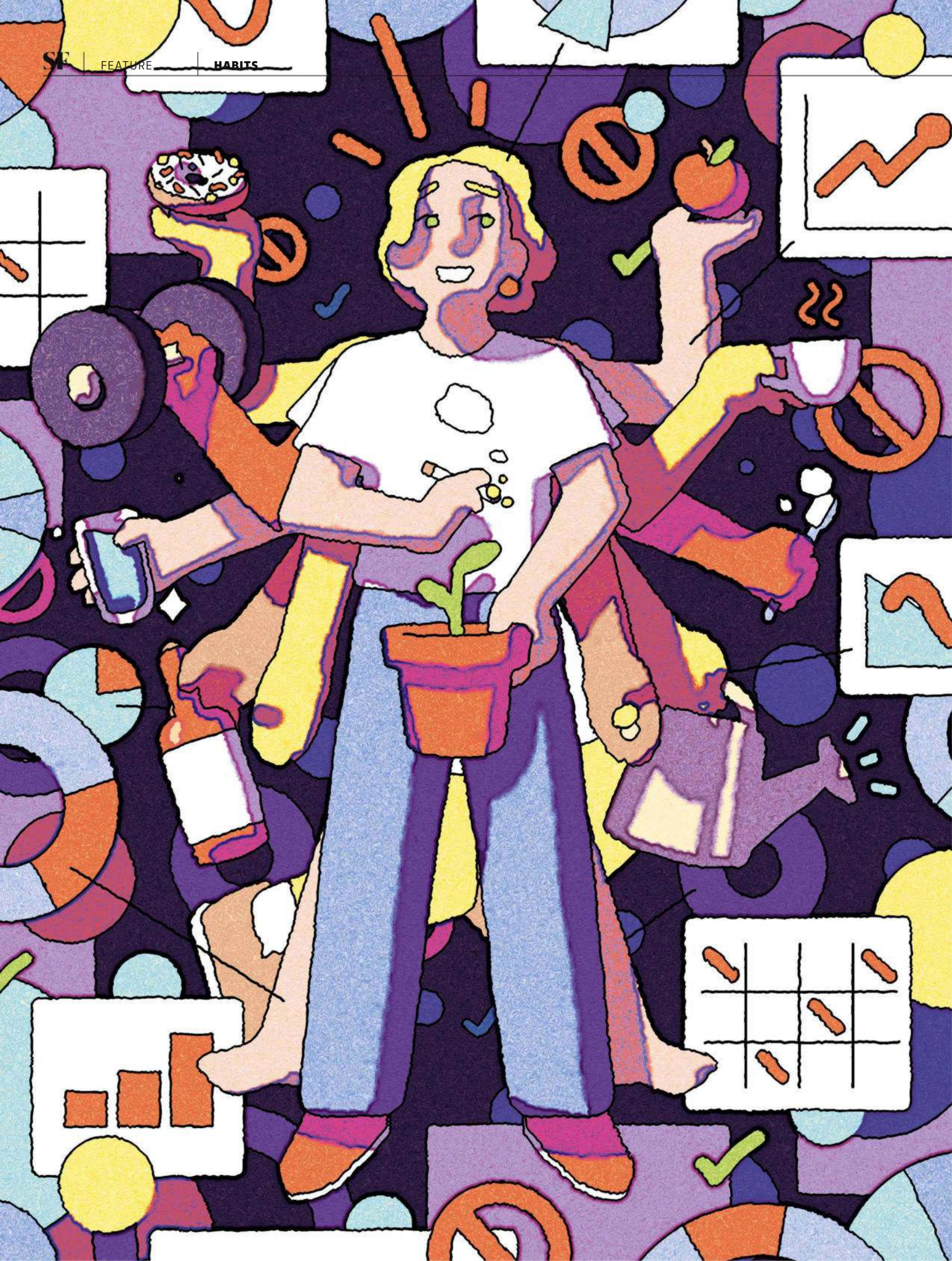
PACU FISH

Say cheese! Pacu fish have a mouth full of flat, square teeth that gives them a human-like smile. Sometimes referred to as 'vegetarian piranhas', due to their body shape and colouration, pacu fish prefer to snack on freshwater 'trail mix' instead of fresh meat.

Their molar-shaped teeth do an excellent job of crushing the hard shells of the nuts and seeds that frustrate other animals, providing them with a reliable source of fat and protein despite their plant-based diet. Pacu fishes are the gardeners of the Amazon and play an ecologically important role in spreading seeds throughout the river's tributaries and floodplains.

The most famous of the pacu fishes, the tambaqui, can get as big as a golden retriever. At one metre in length (3ft) and weighing 30kg (66lbs), it's the second-largest fish in the Amazon (after the arapaima). Tambaqui are a popular meal in South America, where it's often sold with cuts on the bone like pork ribs. They also show up in the exotic pet market, though they need an experienced keeper and a truly enormous tank to thrive. **SF**

by **DR BRITTNEY G BOROWIEC**
(@this_is_brit)
Brittney is a zoologist and science writer based in Ontario, Canada. She studies how fish cope with the challenges of low oxygen and other extreme environments.



THE POWER OF HABIT

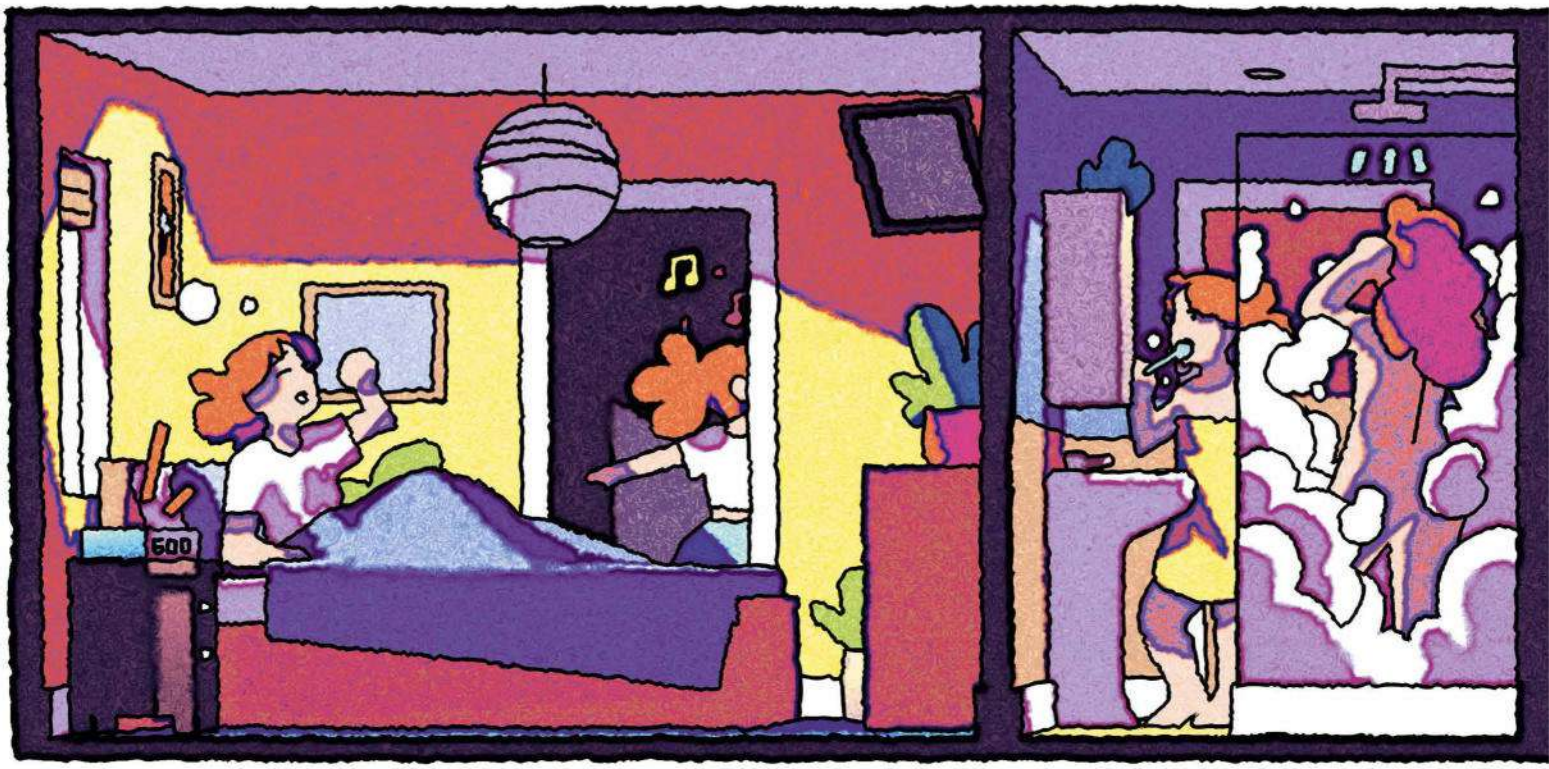
Our lives are filled with habitual behaviours, both good and bad, but how do they form and how can we build better ones?

by **DR CHRISTIAN JARRETT**

The word 'habits' gets thrown around a lot. Your GP encourages you to get into the 'good habit' of eating five portions of fruit and veg a day; your friend worries about their 'bad habit' of checking Twitter before bed; maybe you once had a music teacher who kept on at you to practise your scales until they 'feel habitual'. Or perhaps you've been telling yourself that you want to get 'into the habit' of going to the gym twice a week.

All this talk makes sense at a colloquial level, but psychologists are more pedantic about it. In fact, not everything you do, or aspire to do, frequently or regularly, is necessarily a habit. Some of the situations above are more about goals (what you hope to achieve at some point in the future), intentions (your plans for what you're going to do) and skills (such as being able to hit musical notes consistently), than about habits per se. Routines – such as going to the gym regularly – have the potential to become habitual, but it's not inevitable that they will. So what exactly is a habit? And what does it take to make one that's 'good' or break one that's 'bad'? →

ILLUSTRATION: KYLE SMART



WHAT MAKES A HABIT?

A habit is your brain on autopilot

In psychology, saying that a behaviour has become habitual means something very specific – although there are some niche controversies around the edges of the concept. One key feature of habits has been recognised since at least the time of William James, the American philosopher and historian who's regarded as one of the founders of functional psychology.

As he put it near the start of the 20th century, when it comes to habits, "action goes on of itself". What he meant by that is once something is habitual, you do it without thinking.

Building on that idea, psychologists today say that what makes a habit a habit, is that it's a behaviour, or a related sequence of behaviours, that's triggered automatically by specific cues in the environment.

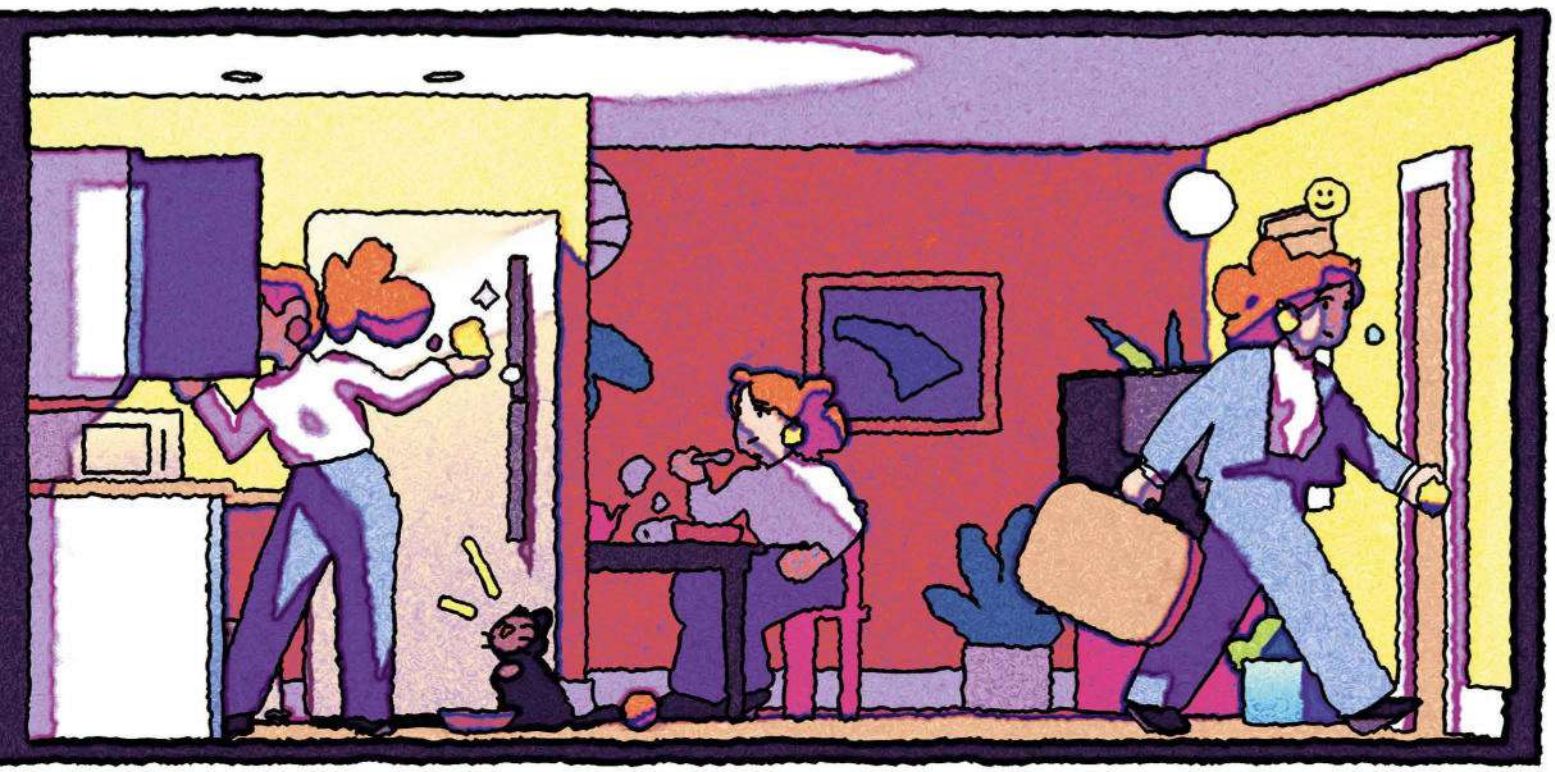
The pairing between the cue and the action might have begun as willful and goal-related, but over time, the association strengthens and now it plays out without thought or volition – even if the behaviour is no longer pleasurable or desirable.

For example you take a sip from your pint at the pub and, without thinking about it (and even though you want to quit smoking), you reach for your pack of cigarettes.

This process of a behaviour in a particular situation starting out as deliberate or purposeful – that is, done to serve a particular goal or because it's rewarding – but then becoming increasingly automatic through repetition, has been shown at the level of brain activity. The more a behaviour becomes an ingrained habit, the more that it comes to be controlled by brain networks that are involved in involuntary action than by networks related to conscious goals and decisions. Or, to put it another way, the decision-making process you once had to go through to perform the behaviour has been bypassed.

It's more efficient that way since the brain only has so much energy and real estate to play with to get stuff done, so if a behaviour is rewarded and sufficiently repeated, it squeezes the decision-making part of the process out of the loop.

ILLUSTRATION: KYLE SMART



Fortunately for us, this decision is gone, but not forgotten. Let's say, for example, you like to have a glass of wine to relax after work. At first, when the behaviour was new, the decision-making process took up a lot of the processing power of the prefrontal cortex (the brain's executive command centre that governs planning and conscious thought).

Clearly such an important part of the brain can't be busying itself with decisions about wine. So as this behaviour is repeated, the decision-making seems to be 'handed off' to a smaller part of the prefrontal cortex, called the infralimbic (IL) cortex, where it looks like habits can be turned on and off.

Scientists from MIT investigated the function of this region by training rats to navigate a maze to reach a reward (some chocolate milk). After enough repetition the rats appeared to make their way through the maze's turns by reflex: getting to the chocolate milk had become habitual. The reward could be removed and the rats would keep running the maze, and even when the chocolate milk was mixed with a nausea-inducing chemical, the behaviour persisted – they ran the maze and didn't drink the milk. The behaviour had become fully habitualised.

Then the researchers used a technique called optogenetics, which uses light to switch on and off the function of certain cells, to turn off the IL cortex – the part of the brain where we think the control of habits resides. With this part of the brain inhibited, the rats almost instantly slowed down as they started to consider each turn in the maze. They had dropped the habit.

This work has led scientists to think that the IL cortex might be a kind of switchboard for our habits, turning them on and off as needed. While we can't start shining lights into our skulls, it does add flesh to the bones of the idea that habits bypass decision-making and that it might be possible to tease repetitive behaviours out of our heads with a bit of conscious thought.

But what really makes habits so interesting to psychologists and other health professionals is the way they can shape our behaviour… for better and worse. The healthy or unhealthy habits you may have can exert an outsized influence on the kind of lifestyle you lead, and on your ability to fulfil your longer-term goals.

So, if you've formed a number of unhealthy habits, the cumulative harmful impact could be significant. Hence the appeal in learning how to break them, or build healthy ones. →

BREAKING BAD HABITS

Take temptation out the equation

Knowing the basic psychology of what makes a habit a habit can provide clues for how to break bad ones and create good ones. To break a bad habit, a good place to start is to think about the specific cues that trigger the habit and then see if you can avoid them or make them less noticeable.

For instance, it sounds obvious, but if you want to break the habit of checking social media when you get into bed, the main trigger is probably the sight of your smartphone. So to break the habit, remove the trigger (leave your phone downstairs). Similarly, if you want to break the habit of pouring yourself a glass of wine after work, consider the trigger – is it the sight of the wine bottle in the fridge, the wine glass on the shelf or something else? Hide these triggers and you'll find it easier to break the habit.

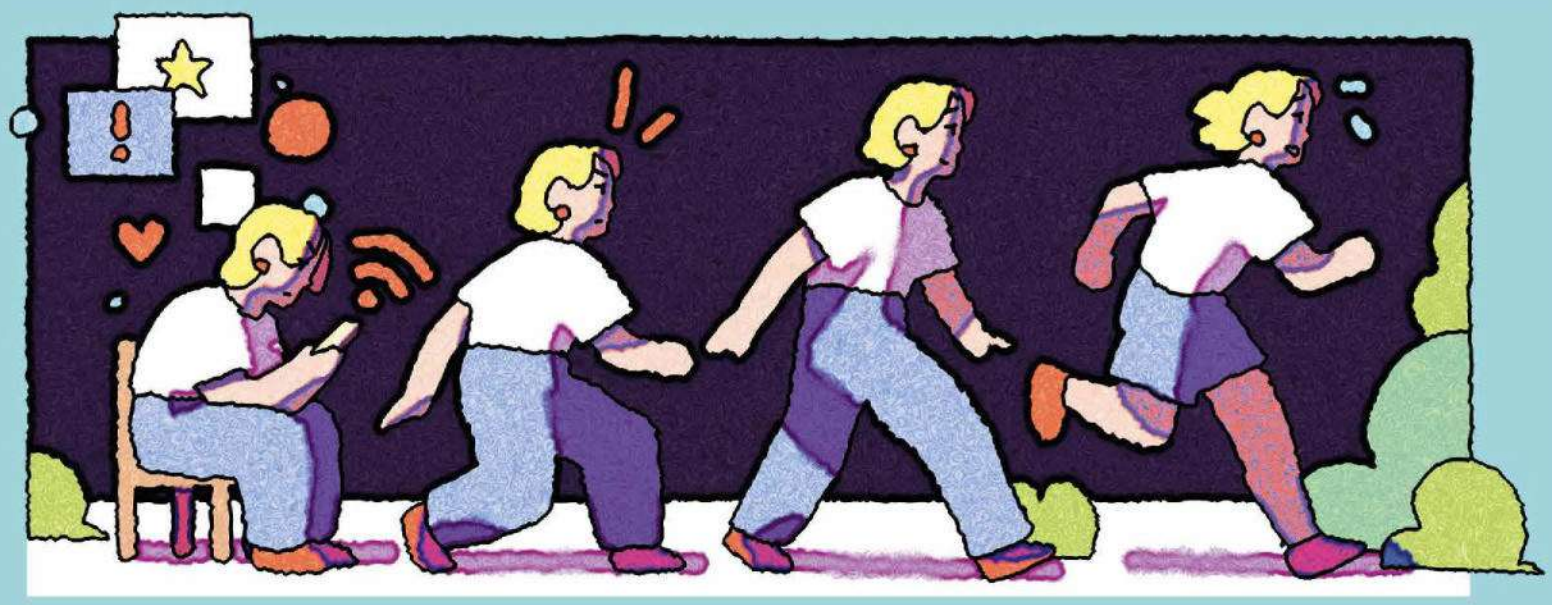
Besides the specific triggers, habits also tend to be embedded in a wider context or routine, so you can make it easier to break a habit by altering them. How far you go is up to you, but at the extreme would be things like moving house or changing job – anything that shakes up the associations in your brain between specific situational cues and past behaviours. (This is why you might find that the habits you have at home lose their power when you go on holiday, because the background cues and context are often profoundly different.)

Another trick is to think about the original function of the now unwanted habitual behaviour. It's likely that there was originally a purpose to it, or it provided some kind of pleasure or reward. But perhaps now your goals have changed, or the pleasure provided is reduced, or you no longer think that the reward justifies the behaviour.

For instance, the after-work glass of wine might have helped you relax or served as a reward after a hard day. If so, consider what other forms of relaxation or reward you could give yourself instead.

The point is, breaking a bad habit will always be easier if you substitute the unwanted behaviour with a new (more desirable) behaviour that serves a similar function, than if you just leave a gap or hole where the old habit used to be.

"BESIDES THE SPECIFIC TRIGGERS, HABITS ALSO TEND TO BE EMBEDDED IN A WIDER CONTEXT OR ROUTINE"



FORMING HEALTHY NEW HABITS

Habits, like Rome, are built in more than a day…

When it comes to making desirable behaviours automatic, you can reverse engineer the psychology behind habit formation. Remember it starts with a behaviour or sequence of behaviours performed repeatedly in response to the same cue(s) or trigger(s). When that pairing is repeated often enough, it can eventually become automatic. So to begin inculcating a new behaviour, take every opportunity you can to repeat it at the same time and place, in the presence of the same trigger(s), so that you start that pairing process in your brain.

For instance, if you want to make a habit of eating an apple a day, it's more likely to stick if you do it at the same time and place – such as having it for your mid-morning snack. It's also going to help to have a bowl of juicy looking apples in sight wherever you happen to be mid-morning, such as by the kettle. Seeing the tasty-looking apples will act as a trigger, so place the fruit bowl by the kettle.

Also, remove any friction between the trigger(s) and desired behaviour. Say you want to make a habit out of going to the gym on your way home from work every Thursday. Think of all the things you could do to ease that pairing, such as choosing a gym that's on the shortest route home, always having gym clothes ready in your work bag, and so on.

Yet another simple trick is to reward yourself in some way for performing the behaviour you want to become habitual. This will help to reinforce the behaviour during the early days before it becomes automatic. For example, let's suppose you want to make a habit out of going for a run at 7am every Monday morning. In the early weeks, you could consistently reward yourself afterwards with a luxurious bubble bath (you've got time because you're working from home that day). Once the run becomes habitual, you'll be able to do without the bath, but the bath will help you repeat the 7am run enough times for it to become a habit.

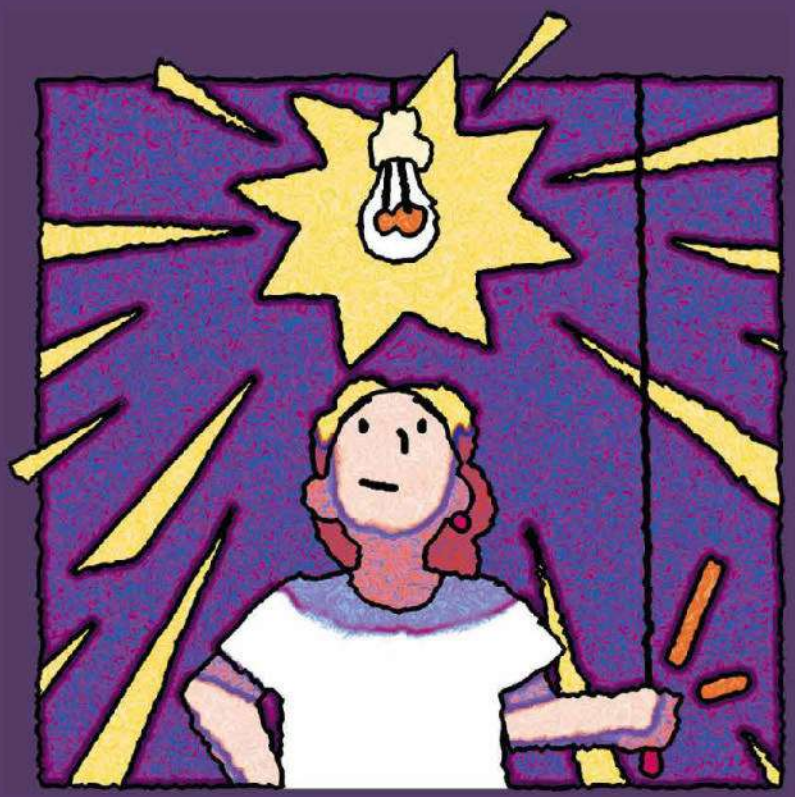
At this point, you might be wondering how many times is 'enough'. Good question.

There isn't a lot of firm evidence on this, partly because there isn't an easy scientific way to say exactly when a habit has been formed. In fact, I've been referring to habits as if they're a singular, all-or-nothing thing, but of course they can vary in their strength, some being more deeply ingrained than others. That said, a much-cited study from 2010, which involved volunteers keeping habit diaries, found that the time taken for a newly performed behaviour (such as eating fruit with lunch) to reach 'peak automaticity' was 66 days, on average. Another study with gym members found that it took at least six weeks, with four gym visits per week, to form a new exercise habit.

In other words, if you want to start performing a new desirable or healthy behaviour, and for it to become genuinely habitual, it's definitely going to take a degree of consistency, dedication and commitment. →

ILLUSTRATIONS: KYLE SMART

EASY WAYS TO HACK YOUR HABITS



SOCIAL MEDIA HABITS

Say no to notifications if you want to focus your attention elsewhere

There's a lot of moralising around our use of devices and social media, but only you know if your phone is stopping you from doing other more important stuff. If you feel it is, one way to take back control is to make your device use less habitual, and the easiest trick in the book for that is to turn off notifications.

Notifications can act like habitual cues that prompt you to check an email or social media message without thinking, potentially initiating a cascade of related behaviours that you didn't consciously intend to do.

Planning to use email, social media or news sites during planned windows of the day is another way to break out of habitual behaviour and ensure your device time is more intentional.

GREENER HABITS

Make it easier to do the right thing (and harder to do the wrong things)

The psychology of habits can help explain why people's behaviour so often fails to change in line with their evolving environmental attitudes, so although many of us recognise the need to adopt more environmentally friendly behaviours, we continue doing the harmful ones anyway. The problem is that so many of our daily behaviours, from transport to consumption, are habitual.

To help people make the change, psychologists suggest methods that draw on habit theory, including reducing friction between cues and more desirable behaviours, and vice versa. For instance, research has shown that office paper recycling shot up when recycling bins were placed near each person's desk rather than having one central bin; and, conversely, people took the lift less often when the doors were programmed to open and close more slowly.

ILLUSTRATIONS: KYLE SMART

BUILDING BETTER LEARNING HABITS

Use one good habit to help other good habits take root

Another method of building habits is to piggyback the desired new behaviour on another that's already habitual.

Imagine you want to make a habit of spending 10 minutes learning German vocabulary every day. Find a habit you already have and piggyback the vocabulary learning on that. For instance, maybe you already have a cup of tea each day at 3pm. Try combining your desired habit with that existing one: so learn the German vocabulary for 10 minutes while you drink the tea.

BUILDING EXERCISE HABITS

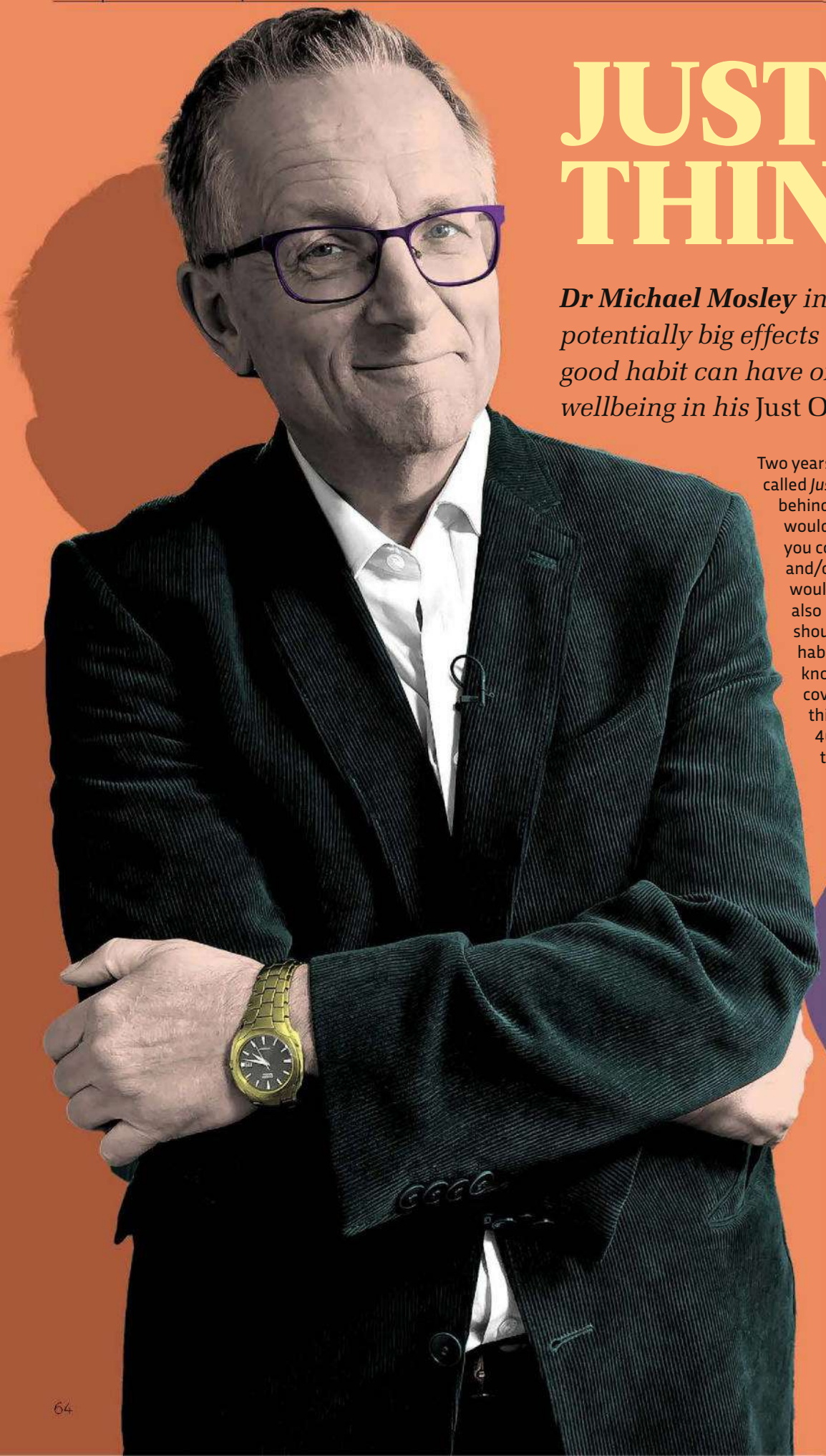
Two minutes a day is all it takes to catch the workout bug

If you currently do no exercise at all, and the idea of forming a new exercise habit seems daunting, then you could try using the two-minute rule. This rule comes from James Clear, the author of the best-selling book *Atomic Habits*. When it comes to forming a new habit, rather than setting yourself a daunting goal, he suggests starting modestly, by doing the new behaviour for just two minutes, which will make it much easier to fit into your daily routine. Then repeat it each day until it becomes a habit. Once it's habitual you can be more ambitious.

So, if you do no exercise now, set yourself the goal of doing two minutes exercise at, say, 8am every day. It could be walking around the garden, a few step ups, a few jumping jacks, whatever. Keep at it, until it starts to feel automatic. From there, you can start to increase the amount gently, to five minutes, 10 minutes, 20 minutes and so on. If you miss a day, don't beat yourself up. Clear says the most important thing is to get back into the routine as quickly as you can. SF

by **DR CHRISTIAN JARRETT**

Christian is a cognitive neuroscientist, science writer and author. He's author of Be Who You Want: Unlocking the Science of Personality Change *and* Great Myths of the Brain.



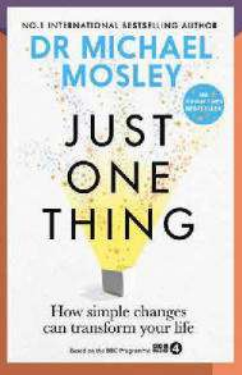
JUST ONE THING

***Dr Michael Mosley** investigates the potentially big effects that one small good habit can have on your health and wellbeing in his* Just One Thing *podcast*

Two years ago I started recording a podcast called *Just One Thing* for the BBC. The idea behind it was that, in each episode, I would introduce you to 'just one thing' you could do to improve your mental and/or physical health. Each thing would often be unexpected, but would also be a quick and simple act that should be easy enough to turn into a habit. I'd talk to a leading scientist with knowledge of the thing we were covering and, of course, I also give the thing a go. We've so far recorded over 40 episodes, but here are the top 10 things that have benefitted me.

BBC SOUNDS

Find out more about Dr Michael Mosley's tips for improving your health and wellbeing on his Just One Thing *podcast*
bit.ly/Just1Thing
and in his book of the same name (available now in paperback)



BBC, GETTY IMAGES X9, ALAMY

Do some push-ups

I start each day by doing push-ups and squats. Moving your body up and down against resistance builds body strength but also increases blood flow to the brain, which stimulates the release of a hormone that encourages the growth of new brain cells and connections. The key is to start gradually and do them properly. Search for 'NHS strength exercises' to get some tips.

Try mindfulness

After my push-ups and squats I often have a cold shower and then try to fit in 10 minutes of mindfulness meditation. What you're trying to do by being mindful is spend a short amount of time each day focusing your awareness on the present moment, rather than worrying about the past or making plans for the future. You can join a course or try out an app.

Take an early morning walk

Besides the health benefits of exercise, an early morning walk also provides you with more exposure to natural light, which will help reset your body clock and regulate your hunger, mood, body temperature and other important bodily processes. Plus, at other end of the day, you'll be more ready to sleep.

Eat some bacteria

In recent years there has been a surge of research into the gut microbiome – the billions of microbes that live in your gut and affect your physical and mental health. Eating fermented foods, such as sauerkraut or kimchi, which are rich in the sorts of beneficial bacteria that can boost your microbiome, can lower stress levels and improve mood scores in just four weeks.

Stand on one leg

After breakfast, while I'm brushing my teeth, I practise balancing on one leg. Doing this helps my posture and should reduce my risk of a fall. Falls are the second most common cause of accidental deaths, worldwide, after traffic accidents. Balance is something most of us take for granted, but it's like muscle strength – use it or lose it!

Take deep breaths

This is one of my favourites, because it's simple, quick and completely life-changing. Just by changing how quickly and deeply you breathe, you can achieve amazing things: you can slow your heart rate, lower your blood pressure, reduce stress and combat anxiety. Try a 4-2-4 pattern; breathe in through your nose to a count of four, hold for two, then out through your mouth to a count of four.

Eat oily Fish

My family eats oily fish at least three times a week. As well as being tasty and wonderfully simple to prepare, oily fish is a really great source of protein and omega-3 fatty acids, which have been shown to be great for reducing chronic inflammation. And reduced chronic inflammation means a reduced risk of both heart disease and depression.

Spend time in green spaces

I live near easily accessible countryside, so I spend lots of time in nature. It's great to just stop, look around, smell of the trees, hear the birds and appreciate the pattern of light passing through the leaves. Studies show that being in green spaces can help reduce stress and anxiety.

Learn a new skill

There's lots of research showing benefits of learning new skills at any stage in life. Taking up video games, learning to dance or trying to paint are all very challenging, particularly when you're my age (66), but it's precisely because they are challenging that doing them has such a powerful effect on the brain.

Read more

I love reading so I don't need any persuading that reading lots of fiction is good for empathy and social skills. Reading can help improve memory and protect against depression, particularly if you can turn it into more of a social exercise by joining a local book club (which I have).

A DISASTER WAITING TO HAPPEN

Earth is blanketed by a swarm of human-made debris hurtling around at speeds of up to 8km per second – about five times the speed of a bullet. The UK's Earth & Space Sustainability Initiative hopes to catch these fast-moving projectiles and clean up the nasty, and potentially lethal, mess our cosmic littering habit has caused

by DR STUART CLARK

Stuart is an astronomer, science journalist and author. He's also a fellow of the Royal Astronomical Society.
DISCLOSURE *Stuart has recently be appointed a director of the Earth & Space Sustainability Initiative and is primarily responsible for the project's communications.*

SCIENCE PHOTO LIBRARY

We used to think of Earth and the night sky as completely different realms. Whereas Earth is lush, green and filled with life, outer space is remote, dark and forbidding. Now we know that is simply not true.

Instead of outer space, we should think of it as near space. As British astronomer Fred Hoyle (1915-2001) was quoted as saying in a 1979 edition of *The Observer*: "Space isn't remote at all. It's only an hour's drive away if your car could go straight upwards."

Our use of satellites for communications, navigation and observation has tied Earth and space together as never before. It's no exaggeration to say that society as we know it could not function without the satellite networks that circle the planet.

Something approaching half of the 195 countries in the world now own at least one satellite. As a result, what happens in space inevitably influences what happens on Earth, and vice versa. Space has become an extension of Earth's environment, a new frontier where human influence is felt.

It's therefore essential that we understand the limits of this new environment and its resources to ensure that our current activities are sustainable, so that future generations can continue to benefit from the unique opportunities that space offers.

A CHANGE OF APPROACH

"I do think we're at a juncture where we need to review what we've been doing in space and consider what's needed for the future," says Joanne Wheeler, managing partner at the London-based law firm Alden Legal, which specialises in satellite, space and communications law.

Wheeler has a background in space law and international environmental law, and has been interested in space debris for around 25 years, having once been the European Space Agency's main lawyer covering issues related to space debris.

Her solution is the Earth & Space Sustainability Initiative (ESSI), a UK Space Agency-funded organisation to establish an appropriate set of principles to outline the responsible use of space, for the benefit of all.

But although the broad themes of the principles have been outlined (see 'The Earth-Space Sustainability Initiative Principles for Sustainabiity', p71) the exact wording of them is still to be decided. "We're taking a holistic, practical, inclusive, multi-disciplinary and anticipatory approach," says Wheeler. In other words, ESSI will consult with the various →

→ industries, universities, governments and other organisations around the world that are interested in space to understand their ambitions, and work with them to draft the principles.

To kickstart the process, Wheeler and her team drafted a memorandum outlining the strands that the principles will focus on. Over three weeks in June, the document was sent far and wide into the worlds of academia and industry for comment, and redrafted several times to reflect the responses. When the finished draft was circulated, more than 120 space organisations, including most of the principal satellite operators around the world signed the document.

"It was remarkable," says Wheeler, "what an excellent way to kick-off the wide engagement we want in drafting the ESSI Space Sustainability Principles. It shows how important the issue is to all space players today."

A DESIGN FOR LIFE

While the principles will cover the entire lifecycle of a satellite, from design and manufacture to its eventual demise, the prevention of space debris is a running theme.

According to the European Space Agency (ESA), as of June 2023, 15,760 satellites have been placed into orbit since the beginning of the space age in 1957. Of these, 10,550 remain in space and 8,200 remain operational.

Low Earth Orbit (LEO), which extends from the top of Earth's atmosphere to an altitude of 2,000km (almost 1,250 miles) is the most congested region. There are roughly 8,600 satellites here, not all of which are still operating.

There are 13,000 pieces of known debris in LEO too. These can be anything from parts of the rockets that put the spacecraft into orbit, to discarded camera covers. Not only do they get in the way of other satellites that we may wish to launch, they pose a collision risk to the working satellites they share space with.

"AS OF JUNE 2023, 15,760 SATELLITES HAVE BEEN PLACED IN ORBIT SINCE THE BEGINNING OF THE SPACE AGE"

Collisions in space are usually devastating because of the speeds involved. Satellites move at around 8km per second (approx 18,000mph). At those speeds, even a small screw can deliver the explosive equivalent of a hand grenade, creating clouds of debris with tens of thousands of fragments, each capable of shattering another satellite.

Unsurprisingly, the UK and others are working hard to avoid such scenarios. "We're investing heavily in both ESA and a number of national initiatives, which range from technology development for in-orbit operations, to design studies that are the first steps towards a national mission to capture and remove two pieces of UK-registered space junk" says Ray

CLEARSPACE, ASTROSCALE X2

TAKING THE RUBBISH OUT... OF ORBIT

The UK Space Agency (UKSA) is championing a national mission to demonstrate that multiple pieces of space debris can be removed from orbit by a single clean-up spacecraft. It has awarded a total of £4 million to Astroscale and ClearSpace to develop separate concepts, before the UKSA decides which to progress to a full design and launch phase. Whichever concept gets the go-ahead will demonstrate, in 2026, the UK's capability to rendezvous and dock with two UK-registered derelict objects in low Earth orbit, before deorbiting them.

Fielding, the UK Space Agency's Head of Space Sustainability.

ESSI is just one of those initiatives. But there are others that are dedicated to 'active debris removal' (ADR), which involves using specially designed spacecraft to capture defunct satellites and throw them back into Earth's atmosphere, where they can burn up.

One of these ADR initiatives belongs to is Astroscale, a Japanese company that now boasts a clean room for satellite assembly in Harwell, Oxfordshire. In March 2021, Astroscale launched ELSA-d, the End-of-Life Service by Astroscale demonstration. This mission consisted of twin spacecraft, a chaser and a target, and demonstrated the way one satellite could capture another using a magnetic arm.

For Nick Shave, the managing director of Astroscale's UK office, solving this problem is about securing the future. "Our strong dependence on space is only going to continue. On our quest to go out into the Solar System, to the Moon first and then Mars, we need to be managing that environment much better," he says.

ClearSpace is another company dedicated to removing space debris. Founded in Switzerland but now building a facility in London, it will launch the ClearSpace-1 mission with ESA and Arianespace in 2026. This will be the world's first actual ADR mission and will remove a piece of a previous Ariane launcher.

"Winning that contract supercharged us as a company into what we are now," says Rory Holmes, of ClearSpace, "The UK is now our our biggest engineering centre outside of Switzerland."

The ClearSpace design features long robotic arms that close around a defunct satellite, holding it while it's fixed, refuelled or removed from orbit.

Both companies are now in a race to win a UK Space Agency contract to remove two more pieces of actual space debris.

MORE SATELLITES, MORE PROBLEMS

The urgency to clean up space has increased with the advent of the so-called satellite mega-constellations. There are proposed fleets of thousands or even tens of thousands of satellites designed to supply high-speed internet from orbit to everywhere on the planet.

Elon Musk's SpaceX-Starlink project is the most high-profile example. As of June 2023, Starlink owns the largest number of satellites in orbit at more than 4,000. →

Space debris in numbers

A BIG PROBLEM, GETTING BIGGER

The number of rocket launches since 1957
6,410

The number of satellites placed into Earth's orbit
15,760

The number of satellites still in space
10,550

The number of satellites still working
8,200

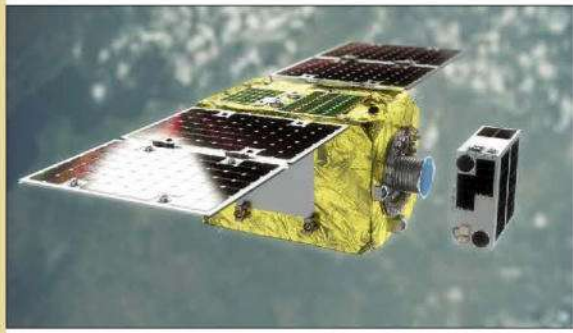
The number of debris objects tracked by Space Surveillance Networks
34,110

The estimated number of break-ups, explosions, collisions, or anomalous events resulting in fragmentation
>640

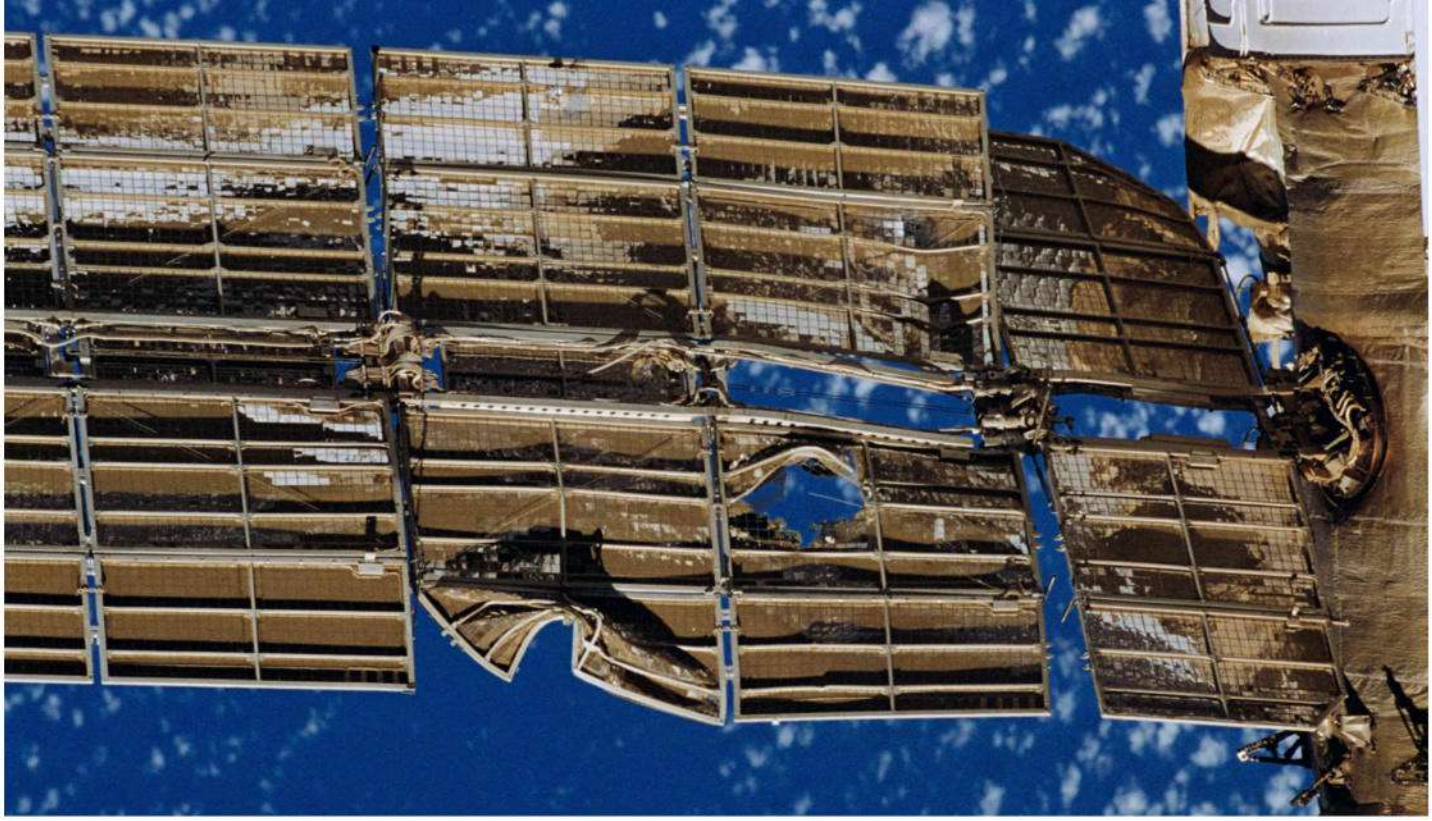
The total mass of all artificial objects in Earth's orbit
>10,900 tonnes

The estimated number of debris objects over 10cm in size
36,500

ABOVE Some of the Astroscale team pose with their ELSA-d debris-clearing spacecraft



BELOW An illustration of the ELSA-d spacecraft, mid mission, about to collect a piece of space debris



"CLEARLY, SUCH A DRAMATIC INCREASE IN THE NUMBER OF SATELLITES AND ASSOCIATED DEBRIS IS UNSUSTAINABLE"

→ And that number is growing all the time. Other companies, such as OneWeb, are launching their own constellations, and Amazon plans to do the same with its Project Kuiper. If everything goes according to plan, more satellites will be launched in the next 10 years than in the entire space age to date.

Clearly such a dramatic increase in the number of satellites and the associated debris is unsustainable. Not only must we remove debris from orbit, but we must also design future satellites to not produce so much in the first place. One option for doing this is to design them to be refuelled and/or serviced, so that their working lives can be extended.

"Can you imagine any other industry where you'd have such an expensive infrastructure you've invested all this time and money in, but you have no way of servicing it, no way of refuelling it? If it breaks, you leave it; when it reaches the end of its life, you abandon it. That has to change. There's so much potential value that could be unlocked if we can master servicing satellites," says Holmes.

ABOVE A collision with an uncrewed resupply ship in 1997 left Russia's Mir Space Station with a badly damaged solar array and forced the people on board to seal off a compartment that was punctured during the impact

Ultimately, of course, it's in every space company's long-term interest to make sure that the orbits around Earth are safe for their satellites to operate in. But Shave has no illusions about other, shorter-term concerns: "Business is always based on generating revenues and, at the end of the day, profits for shareholders."

He thinks about a decision to either pay £X million to perform a clean-up mission, or use that money to buy a ground station for the company. From a short-term profitability point of view, the ground station would always win so what's going to drive that decision towards the sustainability option?

"There's goodwill," says Shave. "But I think the real thing that's going to drive this market is regulation."

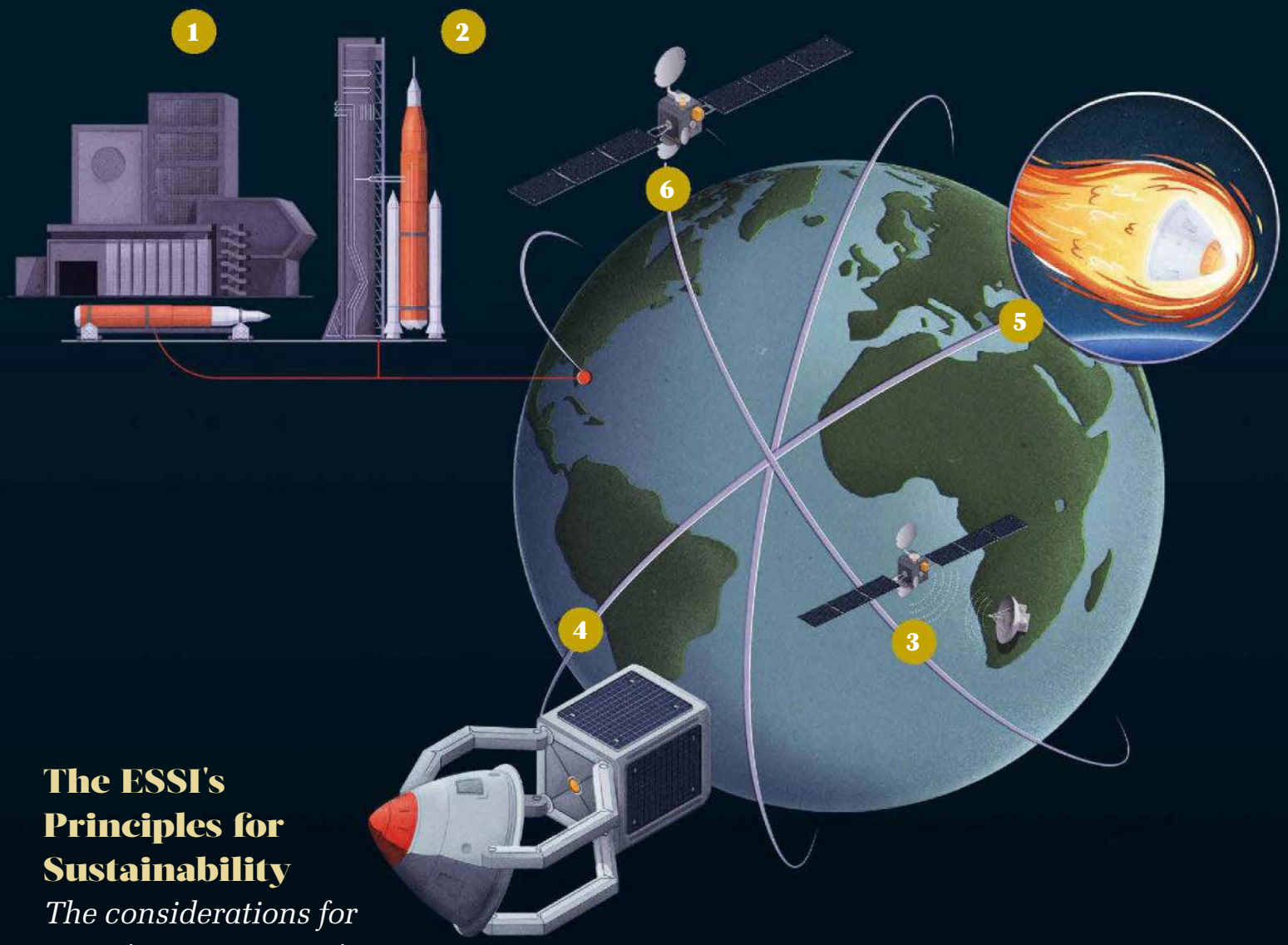
In plain terms, companies must be compelled to clean up their mess. Yet if this option is the stick, then perhaps Wheeler has come up with something akin to the carrot.

"Four years ago, I began thinking about how best to incentivise 'good' behaviour and what good behaviour actually is," she says of the seed of the idea that has grown to become ESSI. "I was keen to link this to insurance and finance, and licensing requirements because I hadn't seen space sustainability issues linked in this way."

Her thinking was influenced by the fact that it's becoming increasingly common for financing and insurance on Earth to be linked to a company's commitment to sustainability, so why not in space too? Time will tell if the approach is as successful, but negotiations have already started over how to turn ESSI's Space Sustainability Principles into internationally recognised industrial standards, so that companies can be measured against them.

In the meantime, we stand on a watershed in history: never before have we possessed the means or the motive to launch so many satellites and use them in such a wide variety of ways to benefit life on Earth. While the cultural, scientific, engineering and economic benefits of using space are unquestionable, they must be balanced against the inevitable environmental and, subsequently, human cost. **SF**

NASA ILLUSTRATION: DANIEL BRIGHT



The ESSI's Principles for Sustainability

The considerations for ensuring space remains a useable resource

1: Spacecraft design and manufacture
How can manufacturers ensure safer satellites that use less resources to build, and minimise their impact on the space above Earth?

2: Launch and propulsion
How can satellite launches be made safer and how can rocket fuels be made greener to minimise environmental impacts?

3: Supporting operations in space and spectrum sustainability
How can space traffic be more effectively managed and controlled? Similarly, how can the limited amount of radio frequencies be used most effectively to maintain communication with the ground?

4: Rendezvous and proximity operations
How can we safely rendezvous with existing satellites to either remove them from orbit, or refuel them so they can continue their missions?

5: Supporting 'end of life' and disposal
How can satellites best be disposed of and what are the environmental impacts of space hardware re-entering Earth's atmosphere?

6: Space debris mitigation
How can satellites be designed to minimise the possibility of them becoming, or otherwise creating, space debris during or at the end of their functional lives?

7: Dark and quiet skies
How can we minimise the visual trails across the night sky and the radio frequency interference from satellites for both cultural and scientific reasons?

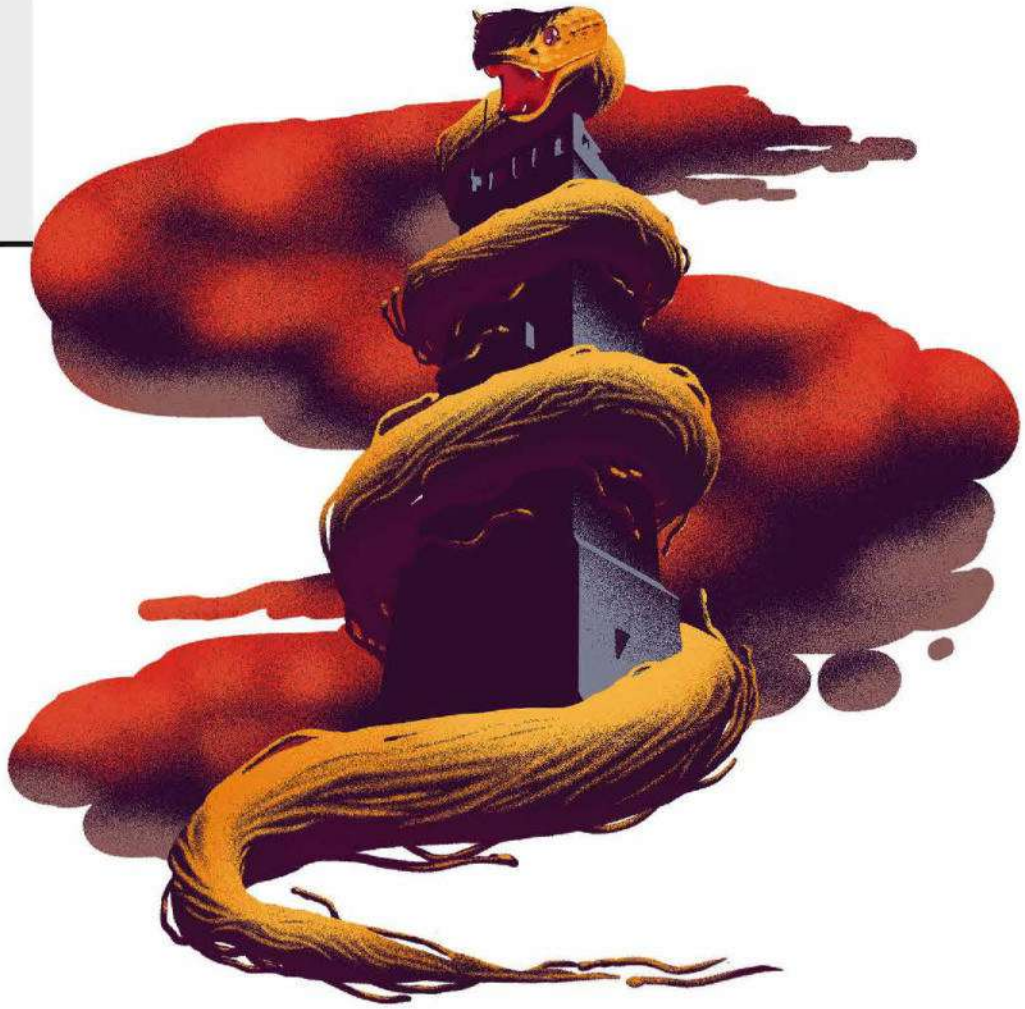
8: Earth monitoring
How can we best monitor Earth to ensure adherence to environmental regulations, and also monitor space weather to warn against adverse effects to satellites?

9: Resource management
How can we make the best use of planetary resources and protect neighbouring worlds from biological contamination?

Q&A

Email your questions to questions@sciencefocus.com or submit them on Twitter at @sciencefocus

YOUR QUESTIONS ANSWERED



ROSEMARY NORTON, VIA EMAIL

WHAT SHOULD I DO IF I GET STRANDED ON SNAKE ISLAND?

Just off the coast of southern Brazil lies the island of Queimada Grande, known as 'Snake Island'. Covering just 43 hectares (106 acres), this rocky island is home to between 2,000 and 4,000 highly venomous golden lancehead vipers (*Bothrops insularis*), which can grow to 70cm (just over 2ft). The snakes were trapped there around 11,000 years ago, at the end of the last ice age, when rising sea levels cut them off from the mainland.

No mammals live on the island, so the snakes had no predators to keep their numbers in check, but also very limited prey. With few ground animals to hunt, the snakes became specialists in catching birds that visit the island during their annual migrations.

This diet may explain why their venom is so deadly. Whereas most venomous snakes have the luxury of biting their prey and tracking it until it succumbs to the venom, the golden lancehead needs to kill their prey quickly, before the bird has a chance to fly off.

Golden lancehead venom is fast-acting and causes a range of horrifying symptoms, from kidney failure to internal bleeding and tissue death. However, these deadly properties have prompted some researchers to investigate the venom for medicinal uses, such as treating heart disease and blood clots.

Perhaps unsurprisingly, the island is uninhabited (by humans), and the Brazilian Navy has forbidden visitors, except for authorised scientific expeditions. This is as much to protect the snakes as it is to protect unsuspecting tourists – found nowhere else on Earth, golden lanceheads are considered critically endangered. Extremely determined wildlife smugglers make illegal visits to capture the snakes, however, as their potent venom is prized on the black market.

A few brave inhabitants did live there in the early 1900s – tasked with running the

DR HELEN PILCHER
Biology

PETE LAWRENCE
Astronomy

DR CHRISTIAN JARRETT
Psychology

DR ALASTAIR GUNN
Astrophysics

DR CLAIRE ASHER
Nature

DR NISH MANEK
Health and medicine

DR EMMA DAVIES
Food and chemistry

CERI PERKINS
Environment

LUIS VILLAZON
Engineering and tech

lighthouse – but legend has it that the family was killed by snakes, and the lighthouse has since been automated.

The golden lanceheads favour forested areas of the island, where they can hunt their prey. Some estimates suggest that in the forests there may be as many as one lancehead per square meter (10ft^2). Scientists say that their numbers are decreasing, however, due to habitat loss, disease, illegal poaching and the negative effects of inbreeding in this isolated population. A much smaller, non-venomous snake known as Sauvage's snail-eater (*Dipsas albifrons*) also lives on the island.

So, if you ever find yourself stranded on Snake Island, your best bet is to avoid the forests and stay on the rocky shore, where you're unlikely to bump into a golden lancehead. If you venture into the forest, watch out for vipers overhead and on the ground. Edible plants and animals are limited, but you could eat one of the snakes (if you

"GOLDEN LANCEHEAD VENOM IS FAST-ACTING AND CAUSES A RANGE OF HORRIFYING SYMPTOMS FROM KIDNEY FAILURE TO INTERNAL BLEEDING"

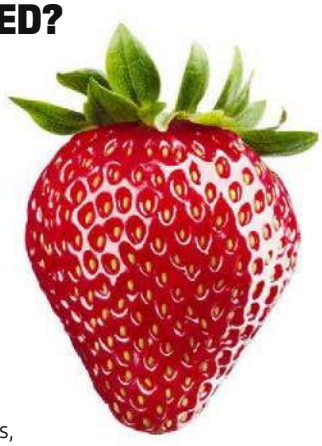
can catch it). Just be sure to remove the head, where the venom glands are located, before you tuck in.

If you suffer a golden lancehead bite, you'll need to get medical attention very quickly: the venom can kill in under an hour, although only around seven per cent of people die. The island is patrolled by the Navy, so a speedy rescue isn't impossible. ***CA***

GETTY IMAGES X2 ILLUSTRATION: BERNARD LEONARDO

GINA HILL, VIA EMAIL

WHY ARE STRAWBERRIES RED?



Substances called anthocyanins give strawberries their luscious red colour. The same water-soluble pigments also tinge some autumn leaves red.

Studies have identified more than 25 different anthocyanins in strawberries, with levels changing depending on the variety. The main one is pelargonidin-3-glucoside, which gives a bright red colour, followed by cyanidin-3-glucoside. Exposing strawberries to UV light after they've been picked increases the anthocyanin levels.

Lab tests have shown anthocyanins to be powerful antioxidants with health-boosting effects, including a reduced risk of cardiovascular disease and anti-cancer properties. It's hard to assess exactly how active the substances are in humans, following digestion, however. Some studies have shown that wild strawberries have higher antioxidant activity than commercial varieties. ***ED***

THOUGHT EXPERIMENT

YOUSEF MEDINA, ROME

HOW MANY PEOPLE WOULD IT TAKE TO BUILD ROME IN A DAY?

The Colosseum of Rome took at least eight years to build, but the Romans could build much faster when they wanted to. Julius Caesar's first bridge over the Rhine in Germany, was built in just 10 days using 40,000 legionaries. It's doubtful that 10 times as many men could have done it in a day though, and building a city is much more complicated. Many Roman residential buildings were six stories high, and you can't build the top floor before the one below is complete. Cement needs more than a day to set and delivering all the materials for every building at once would be impossible along narrow Roman streets. ***LV***

NATURE'S WEIRDEST CREATURES

GREAT EARED NIGHTJAR

Lock up your goats, it's the great eared nightjar; a big-mouthed, teat-wrangling, milk-gobbler of a bird that will desiccate your bleaters and leave them blind. At least, that's what Aristotle thought. According to the renowned Greek philosopher, nightjars suckle directly from the udders of goats. Bear in mind, however, he also believed that eels spontaneously generate from mud, that Earth is at the centre of the Universe and that men have hotter blood than women. Pinch of salt, anyone?

Myths can be hard to shake and so, today, the nightjar is still known to some as the 'goatsucker.' Nightjars, of which there are around 100 species, feed on the wing and are insectivorous. In days gone by, they might have been attracted to domestic livestock, to feed on the insects that associate with them, which is where the nickname may have come from.

The name 'nightjar' refers to the fact that the birds are nocturnal, and that their calls are said to be jarring. The great eared nightjar, known from the Western Ghats of India and parts of Southeast Asia, is so-called because it has great 'ears.' The feathery tufts that protrude from its head, are a bit like the ear tufts of a lynx. Indeed,

the bird's Latin name is *Lyncornis macrotis*, which means long-eared lynx bird.

The Latin name was bequeathed by the Irish zoologist Nicholas Aylward Vigors, who spotted the bird in 1831. This was no mean feat. Like all nightjars, the great eared variety is an expert in cryptic camouflage. During the day, it hides in plain sight among the woody undertones of the forest, where its disruptive colouration – a subtle palette of greys, browns and ochres – helps to break up the bird's outline so it blends seamlessly into the background. Is it a pile of leaves? Is it a tree stump? Is it even there at all? Evolution has sculpted this bird into a true master of disguise.

The great eared nightjar has relatively long wings, short legs, a small beak, but a big gape. Night vision is enhanced by a layer of reflective cells that sit just behind the retina. The *tapetum lucidum*, which is a common feature of other nocturnal hunters such as sharks, crocodiles and cats, helps the bird to see in the dark. When caught in the glare of a torch, it also makes the nightjar's eyes shine, which can be a useful feature for the conservationists who study it.

Adult females lay a single egg in a scrape in the ground, which both parents then brood. When the egg hatches, they continue to feed the chick until it can fend for itself. The birds call at night, but in reality, their song is far from jarring. A sharp 'tsiik' followed by a two syllable 'ba-haaww' is an enchanting and a much-preferred alternative to the call of the bird's Indonesian relative. The Satanic nightjar of Sulawesi is so-called because its call sounds as if it is plucking a person's eyes out! Ouch! ***HP***

CHIEN LEE/NATUREPL.COM; NIGEL VOADEN/WIKIPEDIA ILLUSTRATION: PETE LAWRENCE

ASTRONOMY FOR BEGINNERS

Saturn reaches opposition on 27 August, the Moon a few days later on 31 August. This is how they will appear at 1am BST on 31 August above the southern horizon. Over the nights that follow, the Moon moves east (left) compared to the background stars, but Saturn remains in the same general position.

OBJECTS IN OPPOSITION

WHEN: LATE AUGUST – EARLY SEPTEMBER 2023

Opposition describes an object being opposite the Sun in the sky. For some planets this can be a big deal, as the weeks around opposition offer us the best views of them. At opposition a planet is also visible all night long.

The inferior planets (those with smaller orbits than Earth), Mercury and Venus, can't reach opposition. For superior planets (those with larger orbits than Earth) the effect of opposition decreases with distance.

Nearby Mars reaches opposition every 2.1 years. Most of the time it appears small and distant, but for a few months either side of opposition Mars becomes bright and, through a telescope, its size increases noticeably.

The next opposition of Mars is in January 2025. Jupiter reaches opposition on 3 November appearing brightest to the naked eye and largest through the eyepiece of a telescope for 2023.

Saturn will be at opposition on 27 August and being more distant than Jupiter, its brightness and size changes are less dramatic. Saturn has a trick up its sleeve, however. Its rings are mostly formed of water ice particles ranging in size from micrometres to metres. Away from opposition particle shadows darken particles behind them. But for a few days around opposition the shadows fall in line and become less obvious. As a result if you view Saturn through a telescope, its rings will appear to brighten.

Finally, Uranus (at opposition on 13 November) and Neptune (19 September) lack such tricks and are so distant that opposition has little effect on their overall appearance.

The Moon is technically at opposition when it appears full, as it will on 31 August at 02:36 BST. This is the second full Moon in August, the first occurring on 1 August at 19:32 BST. In popular culture, the second full Moon in a month is known as a Blue Moon, even though it's unlikely to appear blue! *PL*

by PETE LAWRENCE
(@Avertedvision)
Pete is an astronomy expert and presenter on The Sky at Night.

WATCH *THE SKY AT NIGHT* ON BBC FOUR AND BBC IPLAYER
BBC FOUR

MYLES DIXON, VIA EMAIL

WHAT IS BLUE LAVA?

Most people – if they've heard of it at all – are aware of 'blue lava' thanks to the otherworldly photographs of French photographer Olivier Grunewald. The images, which Grunewald captured at the Kawah Ijen volcano on the island of Java in Indonesia, seem to show rivers of electric-blue lava, incandescent against a black velvet night.

Despite appearances, however, it's not lava that produces the striking blue glow. Instead, it's combusting sulphuric gases, which belch from the volcano's many fumaroles at temperatures of up to 600°C (around 1,100°F). When the hot gases hit oxygen-rich air, they ignite and burn with a neon-blue flame. As they burn, some of the gases condense into molten sulphur, which continues to burn blue as it spills down the mountainside. By contrast, Kawah Ijen's actual lava emerges in the familiar red-orange colour you see at other volcanoes.

The flames' distinctive blue colour is caused by a phenomenon called electronic excitation. When the sulphuric gases burn, the intense heat 'excites' electrons within the sulphur atoms. This excited state is extremely unstable and the electrons revert almost immediately to their 'relaxed' state by shedding excess energy in the form of light. All elements emit characteristic wavelengths of light during electronic excitation, corresponding to different colours of the visible spectrum. In the case of sulphur, that colour is the eerie blue-violet that tints the flames at Kawah Ijen.

Locals refer to the phenomenon as Api Biru, or 'blue fire'. Although the blue fire burns around the clock, its flames are difficult to make out in daylight; only as night falls does the spectacle begin to reveal itself. Api Biru is not unique to Kawah Ijen – Grunewald has also photographed the phenomenon at the Dallol volcano in the Danakil Depression in Ethiopia. But the Kawah Ijen's unusually high concentrations of sulphur deposits and sulphuric gases make it the most arresting example and the only one that is consistently burning. ***CP***

RICHARD FULTON, TRURO

HOW DO I STOP POTATOES FROM SPROUTING IN THE CUPBOARD?

If you've ever left potatoes in your cupboard for too long, you might have returned to find them covered in small sprouts, known as 'eyes'. Potatoes are underground plant storage organs, known as tubers, which remain dormant over winter and grow a new plant in the spring. When exposed to light, warmth and moisture, they start to sprout. So, storing your potatoes in a dark, cool, dry, well-ventilated location can slow this process. Another trick is to keep potatoes alongside apples, which release ethylene gas as they ripen. Ethylene slows the sprouting process and helps keep spuds fresh for longer. ***CA***

OLIVIER GRUNEWALD, GETTY IMAGES X3

A SCIENTIST'S GUIDE TO... PILLOWS

THE RIGHT SUPPORT CAN HELP RELIEVE BACK PAIN

Back pain can be hugely frustrating and finding relief for a restful, pain-free night's sleep can make a big difference. Understanding the importance of proper spinal alignment and support during sleep can help, but it can be hard to separate the marketing ploys of bedding shops from genuine advice. Everyone will be different in terms of what they prefer, but there are some general guidelines that could help...

CHOOSING THE RIGHT PILLOW

Selecting the appropriate pillow can make a big difference in managing back pain. You need to see what works for you, but the following advice might be useful:

1 **Supportive pillows** Look for pillows that offer adequate support to the natural curves of your neck and spine. Memory foam pillows or those with contouring features can be beneficial for maintaining proper alignment.

2 **Adjustable pillows** You might benefit from a pillow that has adjustable loft (height) or firmness settings. This allows you to customise the pillow to your individual needs, ensuring optimal comfort and support.

3 **Body pillows** If lower back pain is your biggest problem, placing a body pillow between the knees while sleeping on your side can help align your spine and alleviate pressure.

Regularly replace your pillow every couple years, as worn-out pillows lose their supportive qualities and can exacerbate back pain.

FINDING THE RIGHT POSITION

Getting a good night's sleep can be a huge pain (no pun intended), but sleep is really important for healing and reducing pain sensitivity. The position you sleep in might play a role in promoting spinal alignment and minimising back pain:

1 **Back sleeping** If you prefer to sleep on your back, use a medium-firm pillow that supports the natural curve of your neck and maintains alignment with your spine. Placing a small pillow or rolled-up towel under your knees can help reduce the strain on your lower back.

2 **Side sleeping** If you prefer sleeping on your side, choose a supportive pillow that keeps your head and neck in a neutral position. Additionally, place a pillow between your knees to maintain proper alignment of the spine. Try to make sure the pillow's thickness allows your head to remain level with the mattress, so your neck is not too bent in one direction.

3 **Stomach sleeping** Sleeping on your stomach is generally discouraged when you have back pain, as it can strain the neck and lower back. If this is your preferred position, however, use a thin pillow or no pillow at all to prevent excessive neck extension. Placing a pillow under the pelvis can help maintain a more neutral spinal position and additional support can be provided by placing pillows beneath your ankles.

Again, everyone will be different with regard to their personal preferences, but these general guidelines might help. If one position or pillow type doesn't work for you, don't despair: try to determine which position(s) benefit you the most, and work on those initially. *NM*

RHYS COOMBES, PLYMOUTH

IS IT TRUE THAT WEARING HEADPHONES INCREASES EAR BACTERIA?

Your ears are already dark, moist and full of oils and dead skin – an all-you-can-eat buffet for many bacteria. Sealing off the entrance with headphones or earphones seems like it could only make that environment more inviting to these microbes.

Indeed, a 2008 study at Manipal University in India found that frequent use of earbuds did increase the population of bacteria in the ear – mostly various strains of staphylococcus, a common skin bacterium. And in 1992, a study at the Navy Medical Research Institute in Bethseda, Maryland in the US, found that the kind of over-the-ear headphones used by airlines had 11 times more bacteria after having been worn for just one hour.

As icky as this sounds, it isn't necessarily cause for concern. The headphones in the second study had been sterilised before use, so began with a very low initial bacterial population and that 11-fold increase still resulted in a fairly low number in absolute terms. Also, this increase was too fast to be accounted for by the reproduction rates of bacteria. The study's authors concede that most of the bacteria must already have been present in the deeper skin layers and tucked into the sebaceous glands that produce ear wax. The dark warm conditions while wearing headphones just encouraged them to come out and play.

Furthermore, there's no evidence that these bacteria cause any harm. A 2002 study of call centre workers in Malaysia found no link between headphone use and ear infections. The germs that proliferate in your ear while you listen to music and podcasts, are the ones that live there normally, and your ear is well equipped to deal with them. Several studies have suggested that constantly inserting and removing earbuds or earplugs may increase the risk of skin abrasions that allow harmful bacteria to get in and cause infections, but there isn't strong evidence for this yet. ***LV***

Bloody Science

How can bloodstain pattern analysis help to solve crime scene mysteries?

Infographic by James Round

A violent crime scene can appear chaotic, complex and gruesome. However, in the eyes of a forensic investigator the same scene looks very different. Their expertise can distil meaning from the chaos; a fingerprint can hold a vital clue, hair fibres might offer essential context and the position and angle of a drop of blood might reveal a whole new part of the story. Blood holds a particular value to forensic science because it's predictable. Investigators can use principles from biology, physics and mathematics to understand the placement, distribution and shape of blood, and uncover key information from a scene. Blood is an essential ingredient to life. But to a forensic investigator, it could also be an essential factor in understanding a person's death.

What can blood reveal about a crime scene?

When and where the crime occurred
Blood changes over time. Leaving the body as a liquid, it starts to clot very quickly, resulting in a gel-like substance. Studying the properties of blood throughout a crime scene can help to reveal the chronology of the event.

Who was involved
Blood can be easily linked to an individual through DNA profiling, so the placement of blood in a crime scene can help to show how many people were involved, where they were positioned, and what role they each played.

The injuries sustained and their causes
Depending on the type of injury, blood can drip, spurt, spray or ooze. It also behaves predictably when falling from different heights or impacting at different angles. These factors can identify different types of injuries and what was used to inflict them.

How the other evidence stacks up
One of bloodstain pattern analysis's most vital roles within forensics is corroborating other investigative avenues, such as witness statements and autopsy results. It can also help to confirm or exclude the presence of individuals at the scene.

Blood and the human body

Blood provides essential nourishment, antibodies, oxygen and more.

Blood accounts for about seven to eight percent of an adult human's weight.

1 Low-velocity spatter
AKA passive or gravity bloodstains, these are a result of dripping blood. Drops are over 4mm in size and can pool over time.

2 Medium-velocity spatter
Blunt force trauma or stabbing can cause cast off that moves up to 7m per sec (25ft per sec) and blood spatters 1-4mm (<1in).

3 High-velocity spatter
Gunshot wounds produce spatter that travels at 30m per sec (100ft per sec), causing tiny blood droplets that are under 1mm in size.

4 Expiratory spatter
Blood from an internal injury can mix with air from the lungs and be expelled from the nose or mouth through breathing or coughing.

5 Cast off stains
When a bloodied object or weapon is swung, the blood that's cast off can reveal the direction of the swing, and maybe the number of blows.

6 Void patterns
These occur when something blocks the path of the blood, and can reveal where people and objects were positioned at the time.

Men have around 9-10 pints of blood; women have between 6-7 pints.

Blood is 55% plasma, 45% red blood cells, and <1% white blood cells and platelets.

There are four main blood groups: A, B, AB and O. Nearly 50% of the UK is type O.

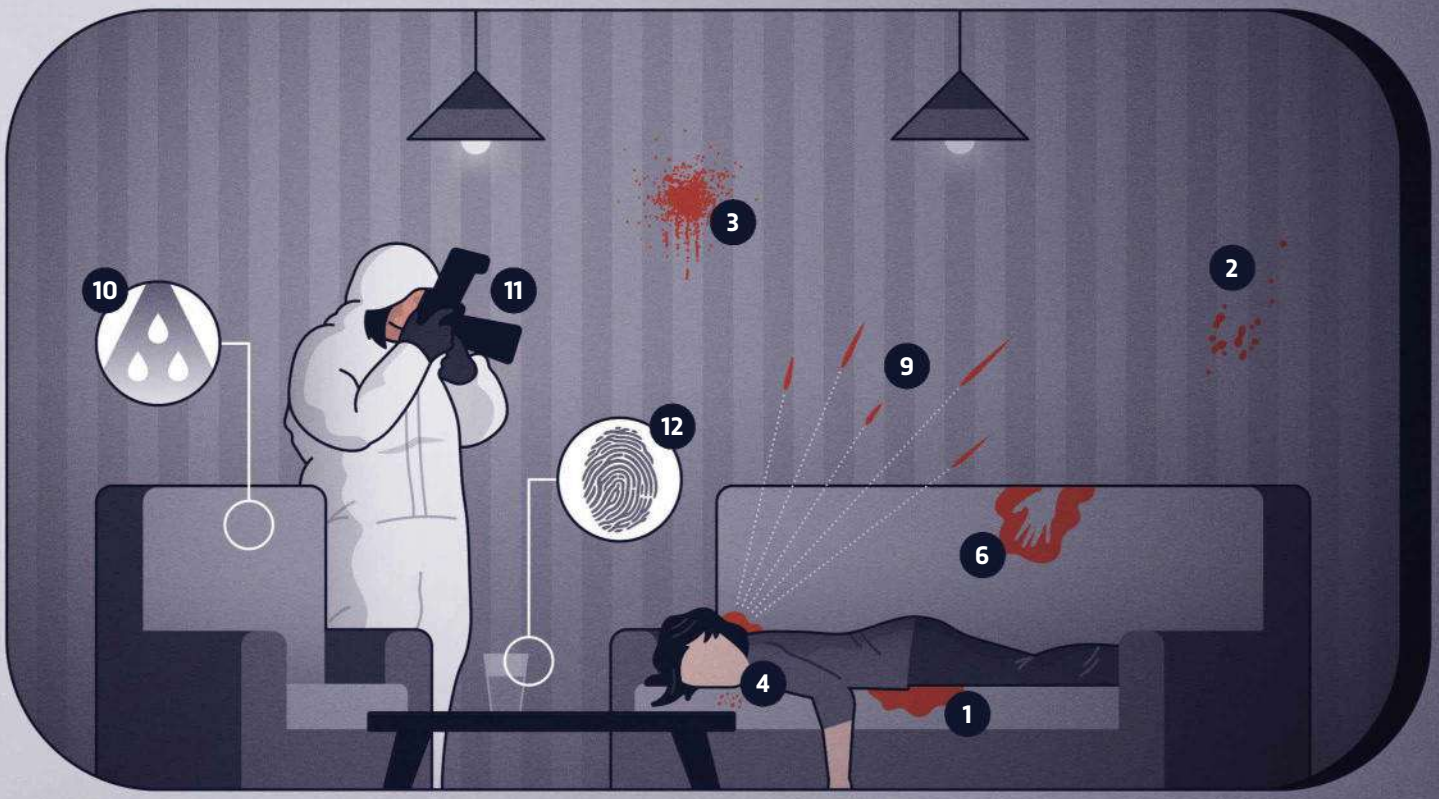
Blood loss of 15-30% will impact your vital signs. 40% will probably result in death.

A short history of bloodstain pattern analysis

The first modern study dates from 1895, when Dr Eduard Piotrowski released a paper about bloodstains due to head trauma. During the 1950s, bloodstain pattern analysis (BPA) played a role in a number of US legal cases, but it wasn't until the 1970s when forensics specialist Herbert MacDonell published the book *'Flight Characteristics and Stain Patterns of Human Blood'*, that the field really took off. Today, BPA forms an important part of forensic science all over the world.

A controversial field of forensics

Despite being a much-used technique within forensic science, bloodstain pattern analysis (BPA) is not without controversy. Over the years, the expertise of specialists like Herbert MacDonell has been called into question and a number of legal cases have been disputed based on doubt around bloodstain evidence. In 2009, the US National Academy of Sciences expressed concern at the field's legitimacy. BPA certainly has a place in forensics, but doesn't have the scientific rigour of other investigative studies, such as fingerprinting or DNA profiling.



7 Transfers

When something touches a bloodstain it may leave an impression, such as a shoe print, which could confirm someone's presence.

8 Wipes

This is another type of transfer, which happens when something with blood on it, such as a hand, brushes against a surface.

9 Convergence

By studying the impact angles of spatter, analysts can trace its path, revealing an area of convergence: the blood's point of origin.

10 Luminol

Bloodstains that are invisible to the naked eye can be revealed with a chemical called luminol, which reacts with the iron in the blood.

11 Recording the scene

Investigators mainly capture the scene through photography, but they may remove certain parts of the crime scene for further study.

12 Other evidence

Investigators will also collect fingerprints, bodily fluids, DNA, witness statements and digital evidence to help to provide a fuller picture.

Sources Cosmos, Forensic Science Simplified, HowStuffWorks, ProPublica, ScienceDirect, US National Library of Medicine, NHS, Wikipedia

DEAR DOCTOR

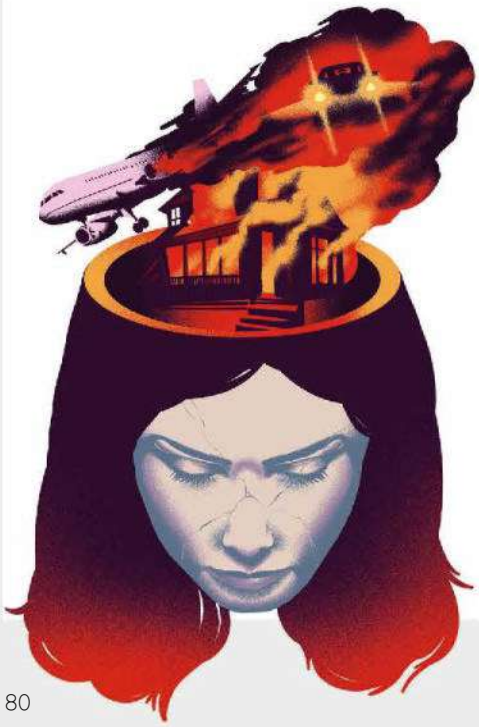
WHY DO I **CATASTROPHISE** SO MUCH AND HOW DO I STOP?

Catastrophe-filled thoughts are common, especially for people prone to anxiety. You might find yourself imagining that your first day at a new job will be an excruciating disaster, that you'll flunk an upcoming exam, or that your flight to New York will crash. These thoughts are unpleasant, but they're essentially your mind working overtime to keep you safe. If you start to act on these catastrophic thoughts, trying to avoid any risk in your life, that's when this thinking style can start to become debilitating.

It's easy to see why we evolved to experience anxiety. If our ancestors had rushed head-first into every situation, they probably wouldn't have survived very long. Anxiety is your brain's way of saying, "Hang on a minute, are you sure this is safe?".

Most experts agree that a modest degree of anxiety and anticipation of potential negative consequences is normal and helpful. It can become problematic, however, when it gets out of hand, and when your predictions become overwhelmingly negative, which is what's happening when you catastrophise habitually.

Instead of weighing up all the possible outcomes and settling on a realistic anticipation of what might happen, you're jumping to the worst-case scenario. You might have learned to think this way because you grew up in an anxious family. Or perhaps bad things have happened to you in the past, which has led you to be highly fearful about the future. Or maybe you're just very anxious by nature and fearing the worst gives you a temporary sense of control – you might feel that, at the very least, you won't be caught unprepared because you've already thought through all the most terrible potential outcomes. Incidentally, research into this sort of 'bracing for the worst' approach shows that it makes people unhappy in the build-up to an event and doesn't offer any protection if things really do go wrong.



If you feel like your catastrophising is getting out of hand, there are a few basic steps, based on Cognitive Behavioural Therapy, that you can try for yourself that might help.

1 Try to step away from your worries Your catastrophic thoughts are fuelled by anxiety, so anything you can do to relax and cultivate calm should help (options include walking in nature, exercise classes and spending fun time with friends).

2 Make time to address your worries Try scheduling a brief 'worry window' in your day – this will help you let the anxious thoughts go at other times because you'll know you're going to come back to them later.

3 Interrogate the evidence for your worries Challenge your catastrophic thoughts by forcing yourself to be as objective as possible about them. For instance, think about other 'first days' that weren't excruciating; remind yourself of the prep you've done for the exam; or read up on the safety stats for flying.

4 Try the 'so what' approach To take the intensity out of your thoughts, you could try challenging the very notion that these things really would be as terrible as you fear. For example, even if the first day on a new job is a nightmare, you'll get over it; you could retake the exam; and people can and do survive plane crashes.

If none of this helps, it's worth consulting a mental health professional who will be able to offer you a more comprehensive plan for overcoming your catastrophising habit. *CJ*

RIA FISHER, VIA EMAIL

WHAT WOULD HAPPEN IF YOU SENT TWO M&MS DOWN THE LARGE HADRON COLLIDER?

The Large Hadron Collider (LHC) is capable of accelerating a proton to almost the speed of light. An M&M travelling at this speed would be devastating. If it hit a solid object, it would release the equivalent of about 80 times the energy from the atomic bomb dropped on Hiroshima in 1945.

Fortunately, this wouldn't happen, because the LHC can only accelerate subatomic particles and nuclei. An M&M is almost 500 trillion, trillion times heavier and even if you could ionise its surface evenly so that it could be accelerated by the collider's electromagnetic fields, the top speed it could reach would be about 6cm (approx 2in) per hour. ***LV***

EVERETT MANNING, VIA EMAIL

IS WATER WET?

The answer to this question requires some philosophical thinking and depends on how you define wetness. The debate over whether water is wet is likely to continue for as long as the planet is awash with the stuff.

Most scientists define wetness as a liquid's ability to maintain contact with a solid surface, meaning that water *itself* is not wet, but can make other materials wet. When you touch a wet surface, the water molecules stick to your skin, creating a wet sensation.

But if you define wet as 'made of liquid or moisture', as some do, then water and all other liquids can be considered wet. Some people describe wetness as a physical, cooling sensation experienced when water takes in energy to evaporate into surrounding air.

The balance between adhesive and cohesive forces determines the degree of wetting. Cohesive forces, such as hydrogen bonds, hold water molecules to each other and create a surface tension. With strong cohesive forces, water tends to stay as spherical droplets to minimise contact with a surface.

Adhesive forces attract the water to the surface of another material and encourage it to spread. If the adhesive forces are stronger than the cohesive ones, then a surface will become wet. Other liquids – such as alcohol – are better than water at wetting. Adding detergents can improve water's wetting ability by lowering the cohesive forces.

The nature of the surface exposed to water affects how wet it will become. Water-hating (hydrophobic) surfaces, such as waterproof fabrics, push liquid drops to have as little contact as possible.

You can define a material's hydrophobicity in terms of the internal contact angle that a water droplet makes with the surface. A perfectly hydrophobic surface is totally water repellent with a contact angle of 180°, while a perfectly wettable surface has a contact angle of zero. ***ED***

QUESTION OF THE MONTH

JOHN KILMISTER, SOUTHAMPTON

WHAT WOULD HAPPEN IF A FIREWORK EXPLODED IN SPACE?

In the vacuum of space, there's no oxygen with which things can burn. Fireworks, however, contain their own oxidiser, which provides the oxygen required for combustion (normally a nitrate compound such as potassium nitrate).

Most professional firework displays use an electronic igniter system. This sends an electric current through a wire to the firework's fuse, igniting it, again without the need for oxygen. So, fireworks work perfectly well in space. But you can't light a firework in the vacuum of space with a flame, as your flame won't burn.

Although, once lit, a firework's propellant fuel burns with its own oxidiser, this is not necessarily true for the pellets of material that are used to create the various spectacular effects and colours seen in today's fireworks. Those combustion reactions, usually using salts of strontium, copper, barium, and so on, generally require additional oxygen, which is normally supplied by Earth's atmosphere. This means that the colours of fireworks in space would be much less bright and fade much quicker than they would on Earth.

Another noticeable difference between fireworks on Earth and in space is that space-borne fireworks would make no sound in the vacuum of space.

On Earth, fireworks reach a limited height due to air resistance and the effects of gravity. In space, however, they would move much faster and further. On the Moon, for example, a rocket could travel six times as high as on Earth. This would mean the most powerful mortar-launched fireworks could easily reach several kilometres above the Moon's surface before exploding. So, fireworks for space would need to be designed to explode sooner than on Earth.

So, without a radical redesign, fireworks in space would be silent, brief, almost colourless and far less spectacular than those on Earth. ***AG***

WINNER

The winner of next issue's *Question of the Month* wins a **trio of hardback popular-science books** (*Growing up Human* by Brenna Hassett; *How Minds Change* by David McRaney; and *Future Stories* by David Christian), worth over £55.

EMAIL YOUR QUESTIONS TO **QUESTIONS@SCIENCEFOCUS.COM**

GETTY IMAGES, CERN ILLUSTRATION: BERNARD LEONARDO

THE EXPLAINER

SHARKS

YOUR ULTIMATE GUIDE TO THESE AWESOME APEX PREDATORS

Sharks were cruising Earth's oceans long before the dinosaurs began roaming the land, and they're still swimming in them today.

Their basic biology is the same as it's always been, with skin covered in tiny teeth and skeletons made not of hard bone, like other fish, but soft cartilage – the same material as your nose and ears.

There are over 500 shark species and they live everywhere, from shallow coastal waters to the deep sea – a few even swim up rivers and into lakes. Scientists are learning more about sharks all the time, finding new species and uncovering new details about their super-efficient, long, slow lives...→

BBC iPLAYER
WATCH
Why Sharks Attack
Available now on BBC iPlayer

DIS

PASCAL KOBEH/NATUREPL.COM

How long have sharks been around?

Sharks can trace their ancestry back at least 400 million years. But it's a myth that all sharks are ancient species. Some are relatively new, including the walking sharks, which evolved in the last two to nine million years.

What do sharks eat?

Most sharks are predators. They hunt for fish and squid, as well as other sharks. Great white sharks have such high-energy requirements that they specialise in eating blubber-rich marine mammals, such as seals and sea lions. Other species, like Port Jackson sharks, crunch on crabs and clams using crushing tooth plates.

A few sharks break the carnivore mould. Whale, basking and megamouth sharks are filter feeders and sift seawater across special structures in their gills to extract tiny zooplankton. Recently, scientists discovered that bonnethead sharks are omnivores. As much as half of their diet is made up of seagrass.

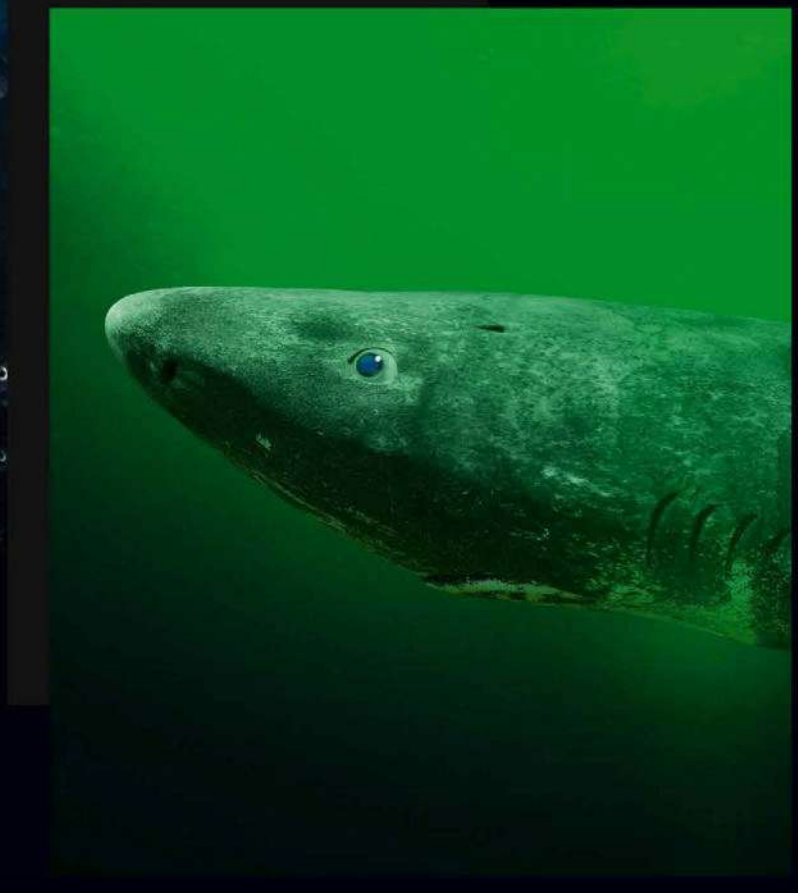
"Depending on the species, sharks can have anything from several dozen, to hundreds of teeth"

How many teeth do sharks have? Why are they so common in the fossil record?

Depending on the species, sharks can have anything from several dozen, to hundreds of teeth. They continually shed worn teeth from the front of their jaws with new ones sliding forwards to replace them. In a lifetime, a single shark can produce tens of thousands of teeth.

The teeth preserve well in the fossil record, much better than their cartilage skeletons, and they tell us a lot about ancient species and ecosystems. A recent study of shark teeth recovered from deep-sea sediments showed that they almost went entirely extinct around 19 million years ago.

Acanthodii, or 'spiny shark' (far left) is thought to be an early relative of today's sharks; a Galapagos shark (left) swims through a school of black-striped salema; Greenland sharks (below) can live for centuries



5 WEIRD SHARK SPECIES

WOBBEGONGS
These masters of camouflage have mottled skin and ragged projections around their snout. As ambush predators, they lie on the seabed and wait for unsuspecting prey to come by.

WALKING SHARKS
Walking sharks stalk the seabed, but they can also hold their breath for up to an hour, so will crawl out onto coral reef flats when the tide is low to hunt for prey trapped in tide pools.

KITEFIN SHARKS
These are the largest sharks that are known to glow in the dark. They live in the deep sea, at depths of up to 1,800m (5,900ft) and may use the lights on their bellies to illuminate the seabed and search for prey.

SAWSHARKS
Sawsharks look as if they've been flattened and had a hedge trimmer fixed to their snouts, which they use to slash through fish shoals. Their 'moustaches' are covered in sensory cells that help them detect prey.

GREAT HAMMERHEAD SHARKS
One of several sharks with T-shaped heads and wide-spaced eyes for excellent binocular vision and depth perception. They spend a lot of time swimming on their sides to save energy (by reducing drag and generating lift from their tall dorsal fins).

DANIELLE DUFAULT/WIKI, CHRIS NEWBERT/MINDEN/NATUREPL.COM, JEROME MALLEFET/NFSR, ALAMY X3, FRED BAVENDAM/NATUREPL.COM, GETTY IMAGES

Megalodon: the giant ancient ancestor of today's sharks

When did megalodons exist?

These giant predatory sharks were prowling the ocean between 20 million years and 3.6 million years ago. Palaeontologists can trace the evolutionary history of megalodons back at least 100 million years.

Are megalodons related to great white sharks?

No. Previously, megalodons were named *Carcharodon megalodon*, which placed them in the same genus as great white sharks. Palaeontologists later decided they weren't so closely related and shifted them to a different group, renaming them *Otodus megalodon*.

What did they look like?

Megalodons are often depicted as enormous great white sharks, but in fact they looked rather different. They likely had a shorter nose than great whites, a flatter jaw and very long pectoral fins that helped support their extra weight in the water.

How big were they compared to animals we're familiar with today?

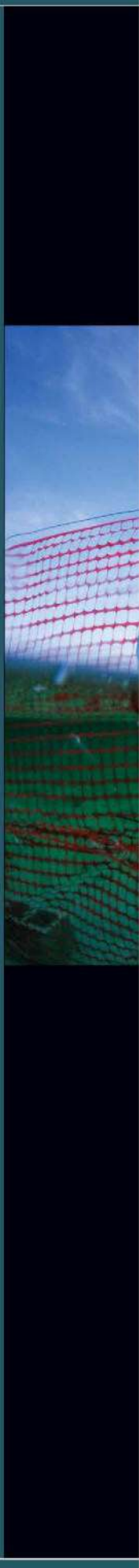
No complete fossilised megalodon skeleton has ever been found, and so size estimates are based on their teeth, which were up to 18cm (7in) long. Experts generally agree that these giants could grow to between 15 and 18m (50-60ft) long, which is comparable to whale sharks, and roughly three times the size of the great white sharks of today.

What did megalodons eat?

Their sharp, serrated teeth show that megalodons were meat eaters. They were top predators that hunted dolphins and fishes, including other sharks. Fossilised whale bones have been found with cut marks of megalodon teeth, and tips of broken teeth lodged in them, showing that the giant sharks were whale hunters too. Their enormous jaws were up to 3.4m (11ft) wide and they had one of the most powerful bites of any predator.

Where did they live?

Megalodons lived all around the ocean in tropical and subtropical waters. A recent study suggested they grew to the biggest sizes in cooler waters.



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"Hammerhead sharks can live for 30 years, and great whites for 70 years"

How long do sharks live?

Sharks are slow-growing and generally long-lived animals, typically taking a decade or more to reach maturity and start breeding. Hammerhead sharks can live for 30 years, and great whites for 70 years. Greenland sharks take this slow pace of life to an extreme. Studies of radioactive isotopes laid down in their eyes when nuclear bombs were tested in the mid-20th century, revealed they can live for as long as 400 years!

Are they endangered? What threats are there to sharks?

More than one third of all known shark species and their close relatives the skates and rays – known collectively as elasmobranchs – are threatened with extinction. They're the second most endangered group of animals after amphibians. The main threat they face is overfishing. Millions are caught by tuna longliners that operate in the remote reaches of the high seas. A lot also get tangled in lines and nets, and caught by trawlers in fisheries closer to shore.

What's being done to protect them? Is there anything we can do at home?

Shark conservation has been gradually improving over the last few decades. Now regulations protect some of the most endangered species. For instance in the Atlantic, longline fisheries must now release all shortfin mako sharks they catch, hopefully some that are still alive. International trade in many shark species is also now regulated. Marine reserves are also being set up specifically to protect sharks, such as the world's first basking shark reserve, off the Outer Hebrides in Scotland.
At home, you can help by not buying any shark products, including obvious things like shark fin soup as well as cartilage supplements that may have come from shark skeletons. If you eat seafood, you can support sustainable fisheries that are less likely to catch sharks as bycatch. Use the Good Fish Guide app to help look for better options. SF

by DR HELEN SCALES
Helen is a marine biologist, broadcaster and science writer. She is the author of What a Shell Can Tell *(Phaidon Press, £16.95) and* The Brilliant Abyss *(Black Cat, £20.71).*

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CROSSWORD

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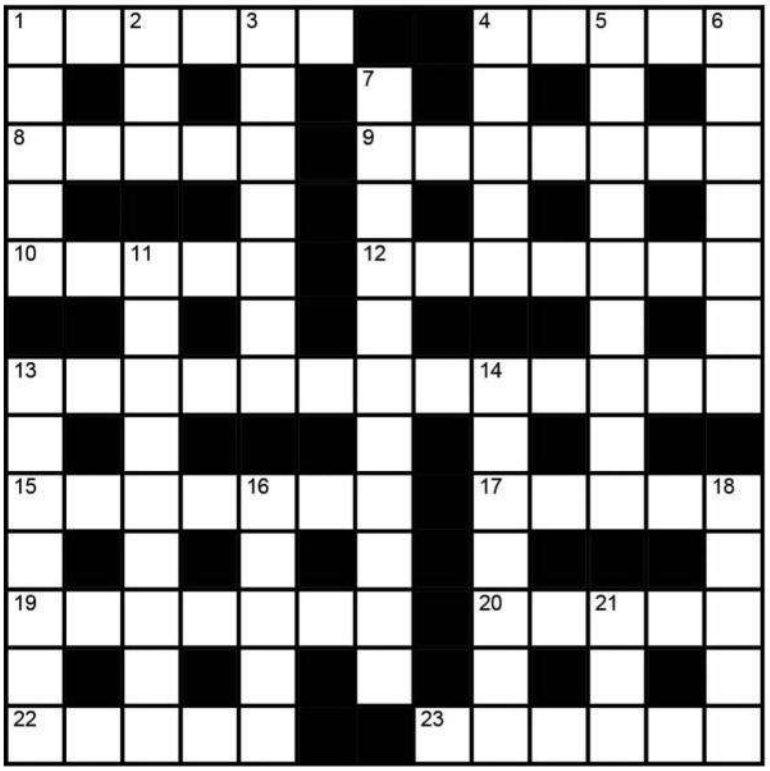

ACROSS

1 Plantation is wrong of the others (6)
4 Uninspired victory paid off (5)
8 Watch merit being eroded (5)
9 Photos aboard ship, I feel worried (7)
10 Costume custom (5)
12 Line expensive, we hear, for a ruminant (3,4)
13 Reported delay, elevating sport (13)
15 Stage of parliamentary debate somewhere in Berkshire (7)
17 Rave about junction and change course (5)
19 Article on Mali's strange creatures (7)
20 Avoid commitment to a boundary (5)
22 Robust writer (5)
23 Hollow pram disturbed it (6)

DOWN

1 Get fellow to engrave (5)
2 Sheep involved in drama (3)
3 Prolong a term at Her Majesty's pleasure (7)
4 Usefulness is universal in glen (5)
5 When most people are watching – 2 or 3 o'clock? (5,4)
6 Nuisance, holding his strange kitchen item (7)
7 Arranged tools, gratis, for stargazer (11)
11 Officer organised a ride after prison (9)
13 Twist new hat on the way to confrontation (7)
14 Achievement gets that woman down, singularly (7)
16 One-time layabout from the country (5)
18 First of taxis on hire for river (5)
21 Salsa, say, and swim (3)

ANSWERS For the answers, visit **bit.ly/BBCFocusCW**
Please be aware the website address is case-sensitive.

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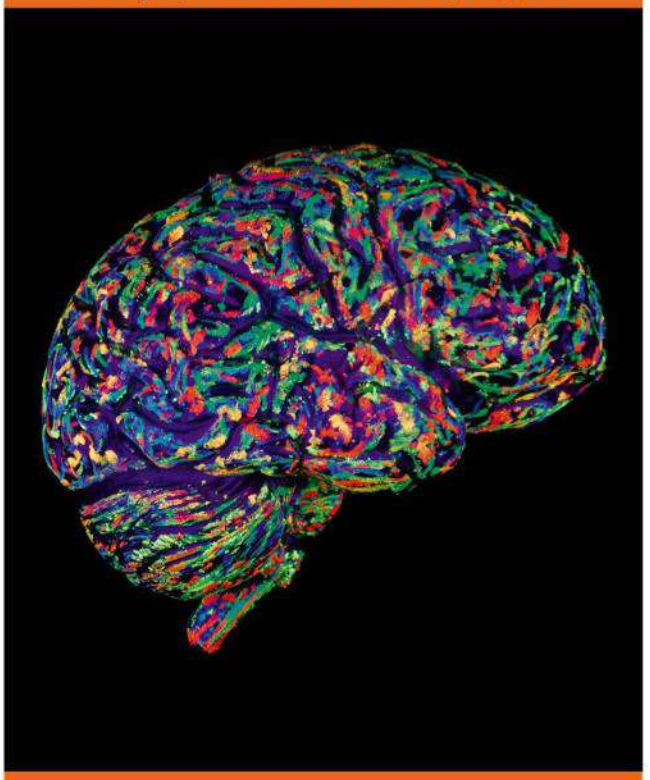
THE BRAIN: EXPLAINED

Your essential guide to the grey matter that makes you, you



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BUG FOOD

Feeding farm animals is a problem. Insects might be the solution

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How psychologists are using psychedelics and virtual reality to treat mental health

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POPCORN SCIENCE

Should you underestimate the power of the Force?

It's an energy that lets you control people's minds and... make things float. So where do midi-chlorians fit in?

by **STEPHEN KELLY**

In *Star Wars: A New Hope*, Obi-Wan Kenobi describes the Force as, "an energy field created by all living things. It surrounds us and penetrates us; it binds the galaxy together." It's a more poetic explanation than the one in *Star Wars: The Phantom Menace*, which suggests that every Jedi has a bad case of worms. Or, to be more precise, that they get their powers from microscopic cellular beings called midi-chlorians.

"The idea that a parasite living in a creature could change or determine the way the host behaves is a very real thing," says Patrick Johnson, author of *The Physics of Star Wars*. "And in theory, that small creature could give the host the ability to do things that they might not otherwise be able to do."

A theory that makes more sense to Johnson, though, is that the Force represents some kind of sophisticated control of electromagnetic fields.

"The fundamental basis of electromagnetic fields is that everything that has a charge (such as protons and electrons) creates an electromagnetic field around it," says Johnson. "And depending on how these particles interact, they can either attract or repel one another."

This could explain how Jedi such as Ahsoka Tano – the hero in the new series *Star Wars: Ahsoka* – are able to move objects around, says Johnson. "So, for instance, if I'm hanging upside-down in an ice cave on Hoth and I need my lightsaber, in theory I could make my hand very positively charged to attract the electrons on one side of the lightsaber and pull it towards me."

But, even if this were possible, it would also require you to be able to focus on a specific object. "Otherwise, you would end up attracting all kinds of things," says Johnson.

One of the most powerful elements of the Force, however, is how it can be used by the Jedi to control others' minds. How do electromagnetic fields play into that?

"In terms of Jedi mind tricks," says Johnson, "our brains have neurons that communicate with one another using electrical signals. Theoretically a Jedi with knowledge of brain chemistry could exert very precise electromagnetic fields to cause certain neurons to fire or not. Let's say the thought 'this is the droid I'm looking for' is neuron one and 'this is not the droid I'm looking for' is neuron two. If I could stop neuron one from firing and cause neuron two to fire instead, that would then create that thought inside of your head."

Johnson is keen to stress that this kind of thought control is highly improbable. There are 86 billion neurons in the human brain and, "it would be very difficult to execute such a precise manipulation of individual neurons – or to figure out what neurons you would need to control. It would require you to map a person's brain to a level that we're currently not capable of."

Even so, that doesn't mean that scientists aren't trying. Johnson references a 2008 study in which researchers asked participants to hit a button with either their right or left hand while recording their brain activity. "The researchers were able to figure out what the brain activity would look like just prior to the subjects pressing the button with their left hand versus their right," says Johnson. "Even stranger, they were able to use this activity to predict which hand was going to be used up to seven seconds before the person made their choice."

So, maybe there's something to the whole midi-chlorians thing after all. **SF**

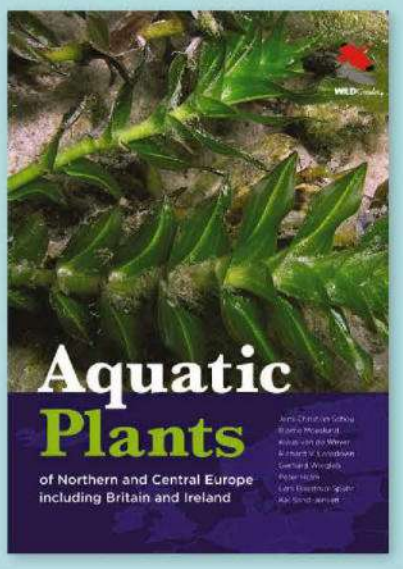
VERDICT

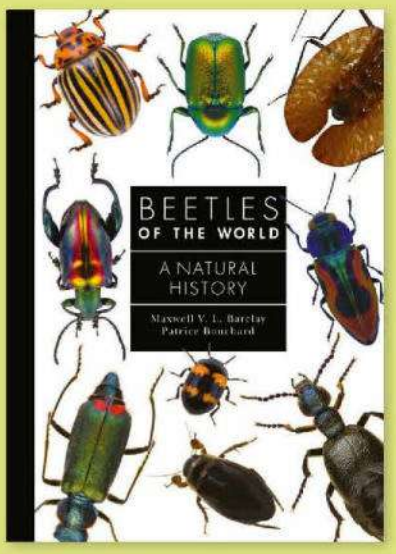
It's not entirely out of the realms of possibility, but a lack of faith in the Force isn't something you should find disturbing.

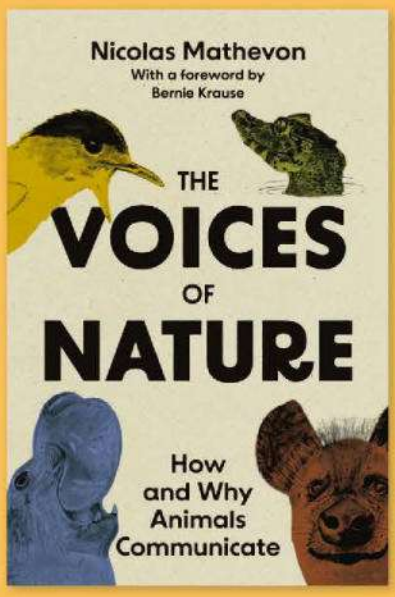
by **STEPHEN KELLY** *(@StephenPKelly)*
Stephen is a culture and science writer, specialising in television and film.

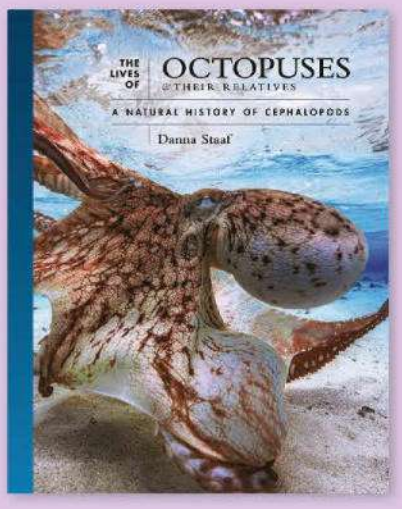
ILLUSTRATION: JAMES OLSTEIN

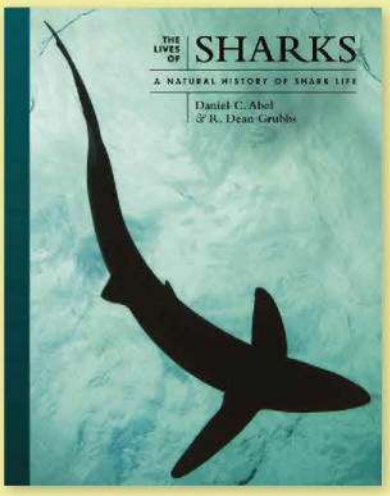
Princeton Nature | *Explore Your World*











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